NASA Student Launch Project
Flight Readiness Review
2013-2014

Citrus College

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I) Summary of Report

1. Team Summary

The Citrus Rocket Owls are a team of 8 students from Citrus College, a team advisor, and a team mentor. The team mentor, Rick Maschek, is Tripoli Level 2 certified (TRA #11388).

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Address: 1000 W Foothill Blvd,
Glendora, CA 91741

2. Launch Vehicle Summary

The team's rocket, Project Lambda, will be 144 inches in length with a 6 inch diameter, and a total pad weight of 52.4 lbs. The vehicle will have two motors staged in line. The first motor, the main motor, will be a Cesaroni K1620-Vmax. The second motor, the sustainer, will be a Cesaroni L985TT. An 85 inch hexagonal shaped ripstop nylon drogue chute will be deployed at apogee to slow the descent to 54 ft/s. At 1200 ft. AGL, a 120 inch main parachute will deploy and bring the rocket's descent to 15 ft/s. The booster section, that detaches to allow the sustainer to airstart, will contain its own 60 inch hexagonal shaped parachute. The rail size for this rocket is 12 ft. and the button size is 1.5 inches.

The Milestone Review Flysheet can be found in the documents section of the team website.

3. Payload Summary

The team has chosen to incorporate the following payloads in the launch vehicle:

Table 1: Payload Selections

Payload Title	SOW Requirement Number
Hazard Detection	3.1.1. 3.1.2. 3.1.3.
CubeSat System (Tesseract)	3.2.2.3.
Lateral Vibration In Line System (LVIS)	3.2.1.1.

The primary objective of Project Lambda is to study triboelectric charging, research and analyze solid propellant rocket motors for in line and parallel staging, and implement a Hazard Detection System for the safe landings of launch vehicles. In order to complete these objectives, Project Lambda will be designed with a Hazard Detection System for safe landings, a CubeSat system for triboelectric studies, and will utilize a multi-stage flight system for staging and motor analysis.

II) Changes Made Since CDR

1. Changes Made to Vehicle Criteria

To ensure all parachutes and electrical components have enough room within the rocket, the length of the rocket has been increased from 130 inches to 144 inches. As such, the pad weight has also changed from 45.5 lbs to 52.4 lbs. This has also changed the predicted altitude from 8000 ft. AGL to an altitude closer to 7000 ft. AGL.

The separation of the booster section from the main bay no longer uses a black powder charge located between two centering rings of the sustainer motor. Instead, the team has opted to use a simpler method, where the black powder charge is located on the bulkhead at the very end of the coupler that connects the booster section to the main bay. However, the PVC case that contains the black powder charge is inverted, and small holes have been drilled through the side of the PVC pipe, so when the charge is ignited, the hot gases will travel outwards to over pressurize the compartment, instead of traveling up and accidentally igniting the sustainer. As a precaution, a piece of masking tape is also placed across the sustainer before launch to prevent premature ignition.

In addition, a PerfectFlite miniTimer4 is being used as a redundant timer to ignite the sustainer. This will be hooked up in parallel with the Raven3, and one lead will go out from that circuit to the RockeTiltometer. The PerfectFlite miniTimer4 is programmed to send out a charge at 2.75 seconds, 0.25 seconds after the Raven3 is supposed to ignite the sustainer. This system ensures that a secondary charge can ignite the sustainer if the Raven3 is unable to do so.

2. Changes Made to Payload Criteria

Hazard Detection

The mechanism of detachment for the detachable bulkhead has changed. In lieu of using nylon cords to secure the detachable bulkhead, the team has devised a safer and more practical method. A heat-treated, copper-toned, anodized aluminum recovery tether will be used to attach the detachable bulkhead to the forward bulkhead of the avionics bay. The tether will contain a set of quicklinks on either side (attached to the detachable bulkhead and forward bulkhead of the avionics bay) that are interlocked via a pin system. A compartment for black powder will be internally located within the tether system, and when the main parachute is deployed, a charge will also be sent to the tether system. The black powder charge will then pressurize the compartment and separate the pin lock system, which in turn, will disengage the detachable bulkhead. Further details on the system are located in Payload Design portion of the report.

Additionally, the payload sleds in the avionics bay have been changed from polycarbonate to birch plywood. Birch plywood is easy to machine with the laser cutter, which produces more precise and exact results. Also, the official scoring altimeter has been changed to a Raven3 accelerometer and its power source has been changed from a standard 9V battery to an advanced lithium 9V battery. The Raven3 can perform multiple tasks, so in order to conserve space, the Raven3 will act as the official scoring altimeter and measure lateral vibrations simultaneously. The advanced lithium battery will produce 25 more mA than a standard 9V, which will help prevent failure of the sustainer motor ignition.

Lastly, the camera used for the hazard detection system has changed. Instead of using the Raspberry pi camera board, a RockSoul USB webcam will be used. The reason for this change is because the Raspberry Pi itself does not recognize its camera board as a webcam, whereas the edge detection algorithm is reliant on a webcam.

Tesseract

Changes have been made to the Tesseract payload as well. Upon testing of the electrometer, this system was deemed unfit to record charge due to major discrepancies in recorded measurements. The system has been replaced with a new circuit that contains a capacitor. The capacitor will be connected to the nose cone and a ground and a new voltmeter system will measure the potential difference across each end of the capacitor.

The signal-to-noise ratio measurements were also scrapped due to the complexity of measuring such signals. Research did not show how something like this could be done so the team decided to move in a different direction and change the research question. The team is now investigating the relationship between triboelectric charging and altitude. Now the altitude sensor data is directly related to the experiment. The coating on the outside of the nose cone has been changed from carbon fiber to carbon paint due to the cost of having a carbon fiber nose cone manufactured. The nose cone no longer has an aluminum tip, because of the lack of availability of resources and

3. Changes Made to Project Plan

Several outreaches were added to the project plan schedule, including the Chinese Institute of Engineers STEM Seminar, and an outreach at the Glendora Public Library.

4. CDR Feedback

1. We like that the team has taken the initiative to make the decision to get rid of the parallel boosters. It's a good learning experience to actively back off of a technical challenge in order to meet the project requirements.

The team sincerely appreciates the feedback, as this is the type of experience and feedback the members were hoping to gain from participating in this research project.

2. What altitude will the rocket be when the booster motor burns out? (booster separates at 730 ft.)

Due to a larger, heavier rocket, the booster now separates at 360 ft.; therefore, the booster motor burns out at about 230 ft.

3. How long after main motor burnout will the command be sent to light the second stage igniter?

The second stage will ignite 2.5 seconds after liftoff, which is 0.97 seconds after main motor

burnout.

4. The RockeTiltometer2 actively records the angle of attack of the rocket. What are the constraints within that algorithm?

According to the user's manual, time constraints have been improved from the first RockeTiltometer as the Direction Cosine Matrix used is specific to "attitude- transformation" and therefore are faster and no longer contain null solutions.

5. Why wait 1.5 seconds after 1st stage burnout to separate the stages?

There will now be a 0.97 second delay between main motor burn out and sustainer ignition.

6. We recommend separating the stages just after main motor burnout, then 1 to 1.5 seconds after main motor burnout, send the command to light the 2nd stage. The motors will probably not come up to full pressure immediately, so the time table from 1st stage burnout to 2nd stage ignition will be close to the same.

After taking this advice into account, the team has changed the delay between the main motor burnout and sustainer ignition to be 0.97 seconds.

7. Are all of the electronics for the sustainer motor in the sustainer?

Yes, the electronics include a RockeTiltometer2, a Raven3 for the airstart ignition, and a backup PerfectFlite miniTimer4, in the event that the Raven3 malfunctions, will all be housed in the Sustainer Motor and Raven3 Trigger (SMART) bay above the sustainer motor.

III) Vehicle Criteria

1. Design and Construction of Vehicle

Design and Construction of Launch Vehicle

Project Lambda is specifically designed to research the following topics: the lateral vibrations of a rocket during its thrust phase; the ramifications of triboelectric charging on communications signals; and the effectiveness of utilizing an edge detection system to relay potential landing hazards. In order to successfully accomplish Project Lambda's mission, key vehicle design features were implemented. These features include: multiple stages to study lateral vibrations; a conductive nose cone working in conjunction with a CubeSat and voltmeter to study triboelectric charging; and a detachable bulkhead that allows the vehicle to reorient itself during its descent phase in order to scan and detect potential hazards on the intended landing surface. The construction methods used to complete these key design features are further detailed below.

Body

Figure 1: Cut Blue Tube

The main sections of the body started as two 48 inch and one 72 inch body tube. The coupler section started out as one 48 inch tube. The sections were measured out and a Miter saw was used to cut the tubes into the desired sizes. The coupler tube was manufactured in the same way. Five different body tube sections were cut and two coupler sections were cut. Extra body and coupler sections were cut out to make two stiffy tubes. This was done by cutting the extra pieces down the length of the tube. Then, another cut was made down the length of the tube. The distance from the first cut to the second cut was calculated so that the stiffy tube would fit perfectly within the coupler or body tube. Using epoxy, the coupler sections were attached to their respective body tube sections. The stiffy tube was also epoxied in, but only after the electronics mounts were built and successfully fit to their sections.

Centering Rings, Bulkheads, and Fins

Figure 2: Laser Cut Centering Rings, Bulkheads and Fins

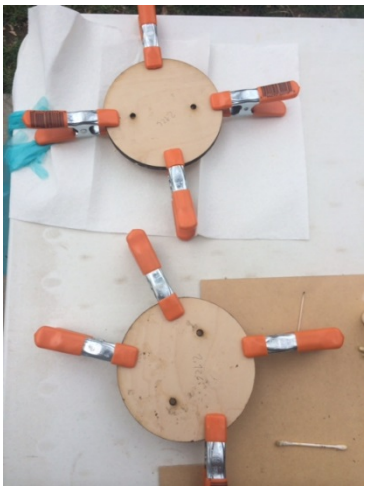


Figure 3: Bulkheads drying

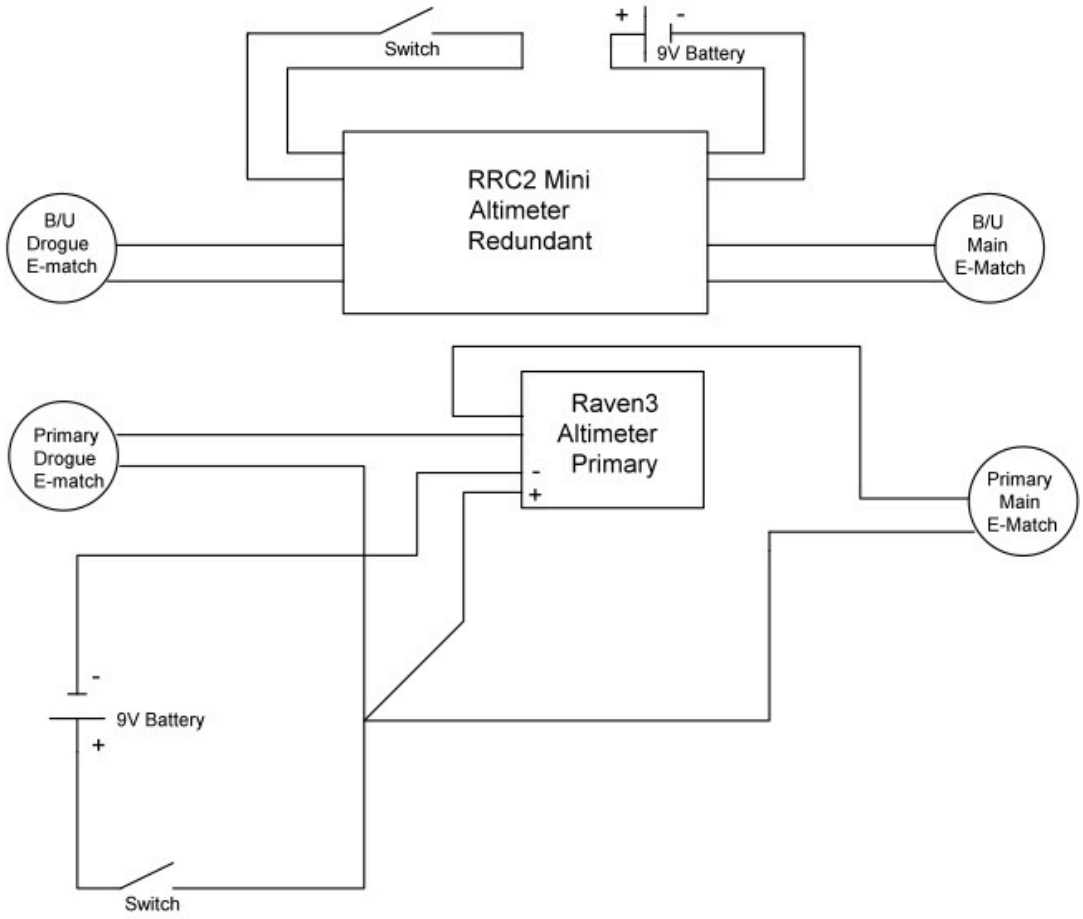
All the centering rings, bulkheads, and fins were drawn out on a Computer Aided Design (CAD) program. The drawings were used by a laser cutter and all of these materials were then cut with a precision of ±0.025 mm. Due to the restriction of the thickness of the wood used, each centering ring and bulkhead was made up of two or four individually cut pieces. For example, the drogue bulkhead, which will experience a significant amount of force during parachute deployment, was made up of four, 1/4 inch, bulkheads that were identical. The four pieces were glued and clamped together to ensure that none of the pieces would be misaligned.

Electrical Elements

a. Avionics Bay

The recovery system incorporates the use of redundant altimeters and black powder charges for both main and drogue parachute bays in attempt to negate the risks of deployment failure. The scoring altimeter will be comprised of a Raven3 altimeter. This microcontroller has the capability of handling up to four events, and can be set to trigger deployment at a specified altitude as pressure is increasing, adjustable in 32 foot increments, or a time delay after initial thrust. A Missile Works RRC2 mini will be employed as a redundancy. This altimeter also has the capability of triggering deployment at a specific altitude as pressure is increasing, adjustable in 100 foot increments, or a time delay after a specified altitude. The Raven3 is set to fire its drogue charge at apogee, and the main charge ate 1200 ft. AGL. The RRC2 mini is set to deploy its drogue and main parachutes 2 seconds after apogee and 1200 ft. AGL respectively. Each altimeter is equipped with its own power source, and the two are wired independently as shown in Figure 4 below.

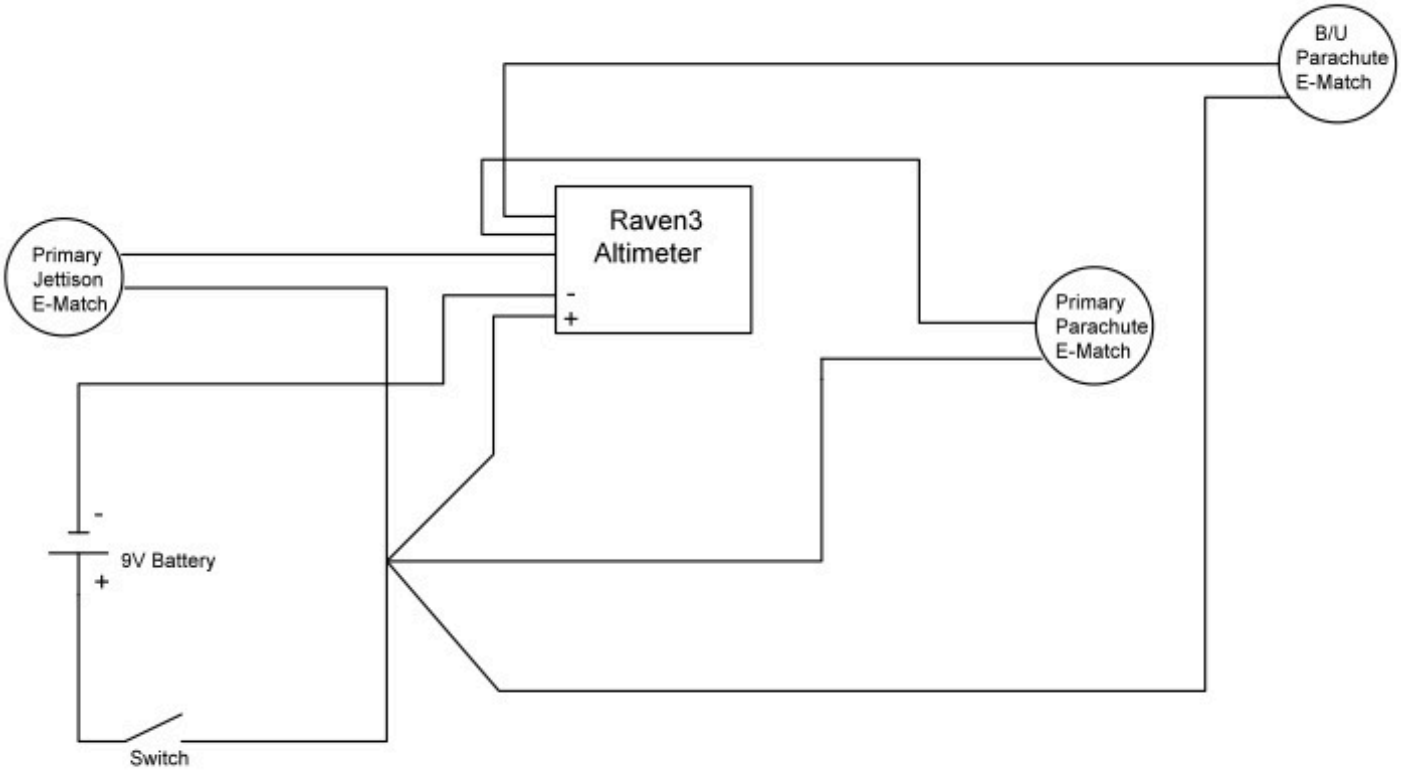
Figure 4: Official Scoring Altimeter Schematics



b. Booster Section

The booster section is designed to jettison from the main airframe of the rocket after main motor burnout. For that reason, it will require its own recovery subsystem. This includes a Raven3 altimeter, which will be located in the booster system to execute all necessary separation commands. This Raven3 is set to separate the booster section from the sustainer two seconds after liftoff, or 0.47 seconds after main motor burnout. It is also programmed to deploy the booster section parachute once pressure starts to increase, or as the booster section reaches its relative apogee. The fourth channel of the altimeter will be programed will detonate the back parachute e-match 2 seconds after the booster section reaches its relative apogee. The wiring schematic for the booster section's recovery electronics are shown below in Figure 5.

Figure 5: Booster Section Altimeter



c. Switches

The on board altimeters are each controlled by independent 2-pole rotary power switches which are installed on the exterior of the payload bays. These heavy-duty switches are equipped with high detent spring-loaded cams to ensure that launch forces do not flip them. Additionally, they are rated for up to 250 V at 6.3A, which will accommodate the altimeter's requirements.

Figure 6: Rotary Power Switch

d. Connectors

A 4-conductor Micro Connector F04-200 has been added to each bulkhead and switch wire. Not only does this guarantee a great deal of ease with regards to electronic hardware integration, but it allows for the altimeters and bulkheads to be detached without the removal of any wiring. Furthermore, these connectors are equipped with a positive locking mechanism. Therefore, the fastener cannot work loose from vibrations induced by the rocket flight.

Figure 7: Micro Connector

e. Battery Retention

All of the batteries used for the altimeters that control the recovery events of the vehicle will be mounted with Philimore 9 V battery holders. These will be screwed into the electronic sleds of each section using #4-40 screws and nuts. The battery allows for soldering points on top of the holders so the wires do not become loose. They also restrict horizontal movement but the team will add additional cable ties for positive retention. The batteries will be oriented in such a way as to have the battery push into place during the thrusting phase.

Drawings and Schematics

The following drawings show the full rocket, as well as different components of each section and how they will come together to form the different sections of the rocket.

Figure 8: Full Diagram of Project Lambda

a. Nose Cone and Drogue Bay

Figure 9 shows the order that the different components of the nose cone and drogue bay will fit together. This section consists of four bulkheads, two of which have a square indentation to hold the CubeSat. There is also a centering ring with a square cutout and an electronics sled. All of these will be held in by three all threads. These all threads will go through 0.25 inch holes cut out in specific places in the bulkheads and centering ring.

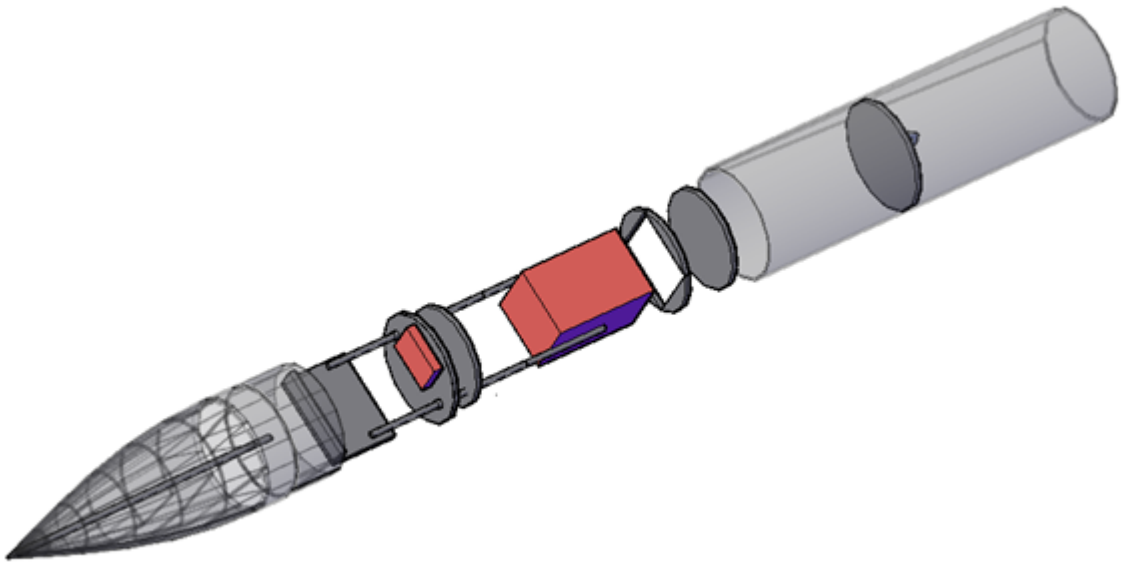


Figure 9: Exploded View of Nose Cone

b. Avionics Bay

Figure 10 shows the order that the different components of the avionics bay will fit together. The coupler tube is longer than the body tube and will hold the electronics. A stiffy tube will be inside and will prevent the electronics from sliding up and down. There will be four bulkheads in this section. All threads will create a solid connection between two of the bulkheads and the stiffy tube and the top most bulkhead will be detachable. It will hold onto another bulkhead through nylon cord. The avionics for the rocket will fit between two bulkheads and the hazard detection will fit between two other bulkheads.

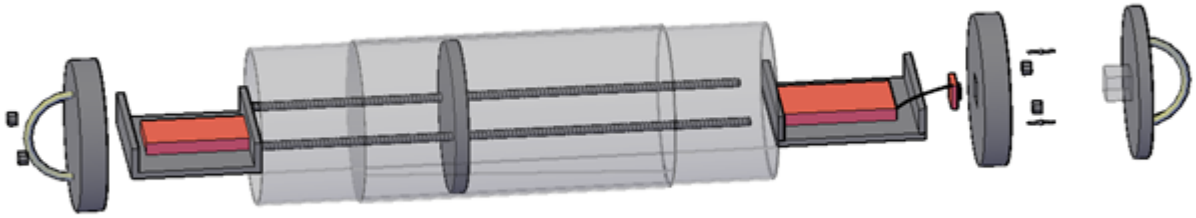


Figure 10. Exploded View of Avionics Bay

c. Main Bay

Figure 11 shows how the different components of the main bay will fit together. The main bay contains 5 centering rings designed to fit a 54 mm sustainer motor. Also, 3 delta fins will fit into slots in the body tube. There will be a bulkhead that will sit directly above the sustainer motor, and a second bulkhead at the very top of the main bay. Between these bulkheads will be the Sustainer Motor and Raven3 Trigger (SMART) bay, which contains the electronics to control the ignition of the sustainer, as well as the recovery system. There will be conduit that will go through the centering rings so that the electronics will have a direct line to the sustainer motor.

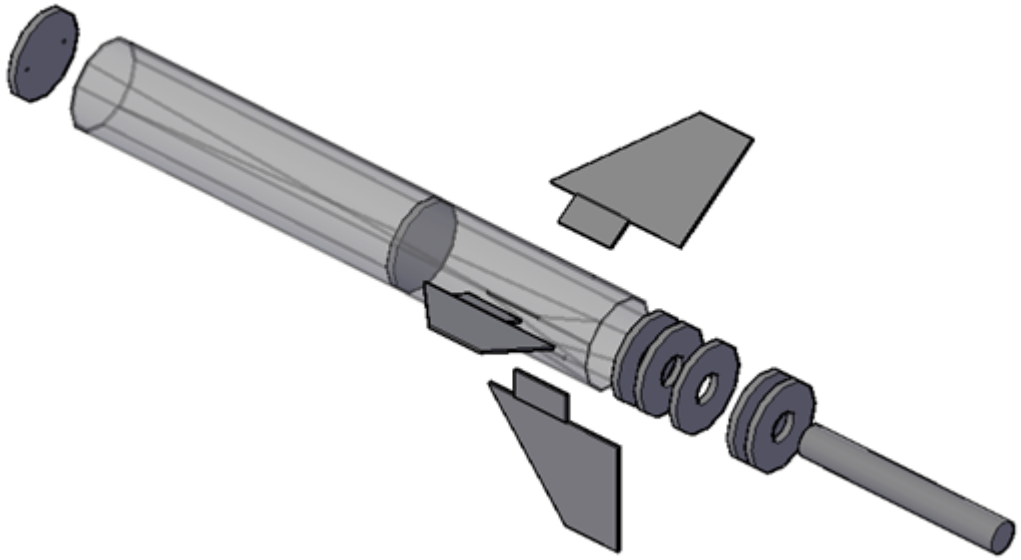


Figure 11. Exploded View of the Main Bay

d. Booster Section

Figure 12 shows different components and how they will be come together to form the booster section of the rocket. This section is comprised of two body tubes which are the upper and lower cylindrical pieces. There is also a coupler tube, which will connect the upper section of the booster to the sustainer and the lower section of the booster. There are 4 centering rings that will hold the motor in the body tube. There are 3 delta fins that will fit into slots in the lower booster section. There are also three bulkheads. A recovery system will fit between the middle and lower bulkhead. The electronics for this section will fit between the upper and middle bulkheads.

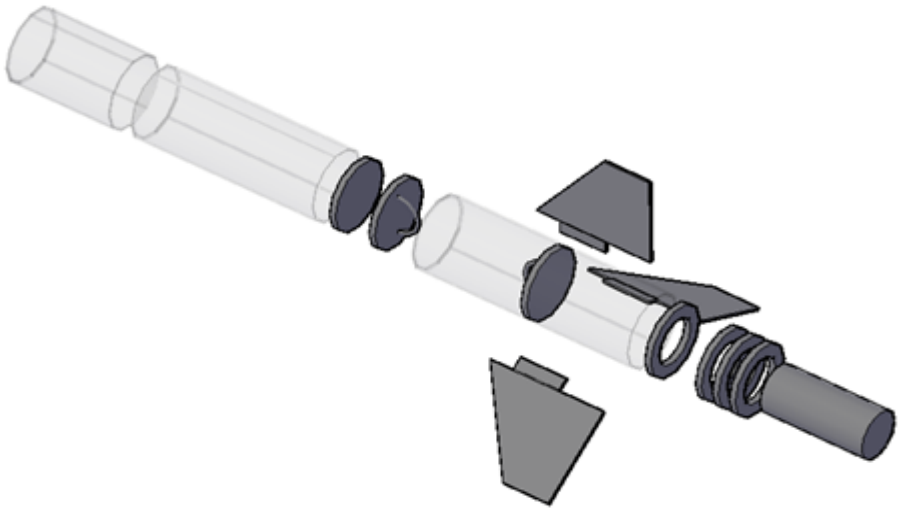


Figure 12. Exploded View of the Booster

Flight Reliability and Confidence

The team's primary objective is to design, construct, and successfully launch a high power rocket capable of compiling data, with the potential to improve future Space Launch Systems (SLS) technology. Project Lambda is directed towards research pertaining to the lateral vibrations of a rocket during its thrust phase, the ramifications of triboelectric charging on communications signals, and the effectiveness of utilizing an edge detection system to relay potential landing hazards.

The rocket will reach but not exceed an altitude of 7000 ft., after which the dual deploy recovery system will bring the rocket to a safe landing within 2500 ft. of the launch pad. All safety regulations defined by NASA's University Launch Project competition as well as team and NAR/Tripoli guidelines will be followed when building and operating the rocket. The Rocket Owls plan to utilize their limited resources to positively represent their school, and community while providing competition for veteran teams.

All the requirements defined by the mission directorate were used to guide the Rocket Owls' design decisions. The team's plan for meeting these requirements will be discussed in the Requirements and Verification section of the Vehicle Criteria, detailing how each design requirement has been met. The team will consider their mission a success after they have both launched and recovered a high-powered rocket built in accordance with the listed design requirements.

The members of the Citrus Rocket Owls have grown vastly in all aspects of rocketry since the beginning of the NASA Student Launch Project. Maturity in design aptitude, particularly, is trait that has been acquired through a great deal of trial and error. Consequently, much of the originally intended design has been scaled back to accommodate all safety concerns, and the reliability and confidence of flight success has increased enormously.

With less risk to mitigate, the team was able to focus attention on two key factors, testing and assembly; which ultimately lead to vehicle reliability and confidence in mission success.

<u>Airframe</u>

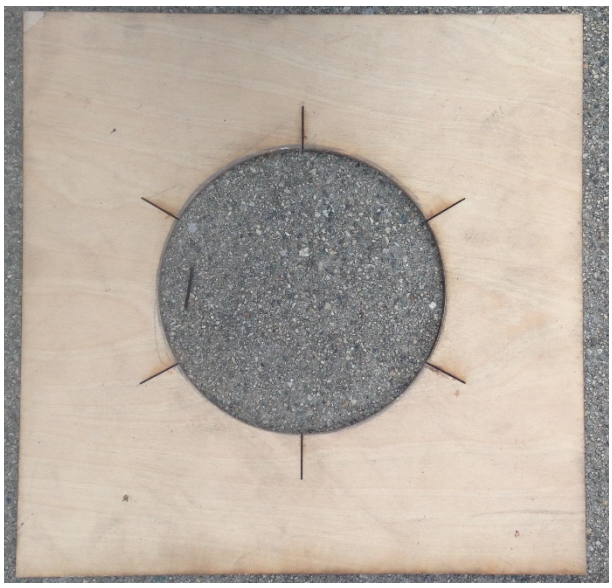
Blue Tube 2.0 was utilized for the assembly of the airframe of the vehicle. This composite material has a high sheer strength, and has been an essential component of many successfully flown rockets nationwide. Nonetheless, it is important to implement a great level of precision during the construction process. For the purposes of this research project, the correct tools were always employed, where the 'correctness' of a tool depends on its accuracy and precision. All body tubes and couplers were carefully cut and sanded. Other critical pieces, such as the fins, were laser cut with $1/40^{th}$ of a millimeter of precision.

<u>Construction Jigs</u>

The team constructed jigs to ensure proper placement and alignment of fin slots and fins. All the jigs were built with laser cut pieces and carefully assembled.

a. Fin Marking Jig

Figure 13: Fin Marking Jig



The Fin Marking Jig, shown in Figure 13, was used to mark the body tube for the fin slots precisely 120 degrees apart. This simple jig consists of a laser cut birch plywood piece with a 6 inch diameter circle cut out of it, and marked every 60 degrees with laser precision ($1/40^{th}$ of a millimeter). The body tube is placed inside the circular cutout, and a line is simply drawn up the side to mark the position of the fin slots.

b. Tube Slotting Jig

The Tube Slotting Jig, shown in Figure 14, was used to create the slots for the fins on both the booster section and the main bay. The body tube was held in place inside the jig, while the router was inserted through the cutout at the top to make a precise slot for the fins.

Figure 14: Tube Slotting Jig

c. Guillotine Fin Alignment Jig

Figure 15: Guillotine Fin Alignment Jig

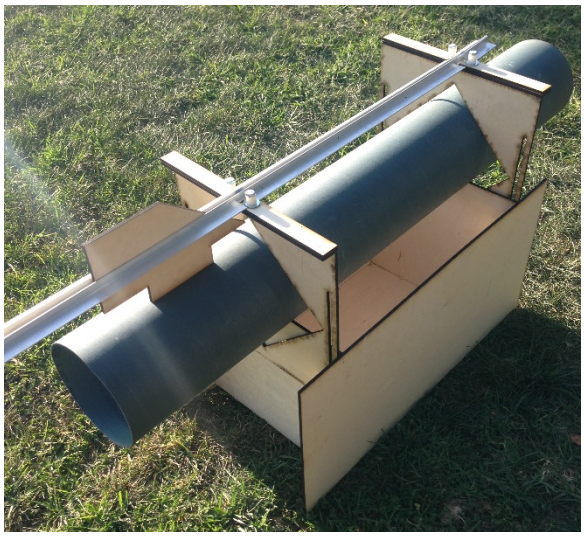


Figure 15 depicts a Guillotine Fin Alignment Jig, constructed based on a design provided to the team by Ted Macklin of Apogee Rockets. The rocket's airframe rests inside the jig, while the fin is inserted through the steel guiderails at an angle precisely 90 degrees from the rocket airframe. The fin is then held firmly in place until the epoxy cures, thus ensuring maximum precision in fin alignment.

Hardware

All electronic hardware pertaining to the scientific payloads and recovery systems were thoroughly tested before implementation into the full scale rocket. This includes, but is not limited to, the Raven3 altimeters responsible for all black powder separations, the RRC2 mini altimeter utilized as a redundancy for main and drogue bay separations, and the PerfectFlite miniTimer4 which will be used as a redundancy to airstart the sustainer motor, Testing and calibration was performed to ensure that all hardware functioned accurately and precisely according to manufacturer specifications. Furthermore, all electronic beds were carefully assembled so as to ensure that expensive electronic equipment is not damaged or dislodged during flight.

Test results, particularly from the subscale test, show that the accelerometer-based altitude readings recorded by the Raven3 altimeter were not accurate. However, further research indicated that the manufacturer expected a high level of inaccuracy in these values. As a result, barometric altitude data is utilized in post flight analysis.

Testing also revealed that the onboard camera that accompanied the Raspberry Pi did not work in collaboration with the custom edge detection algorithm to scan for potential landing hazards. Instead, a USB webcam was integrated, and the hardware problem was alleviated.

Software

All software packages were custom designed by members of the Citrus Rocket Owls. To ensure that commands will be executed as planned during flight, the software was heavily tested not only through static tests, but also in motion as to simulate flight conditions. Further information about software testing and reliability can be found in the payload testing portion of the design review.

Recovery System

In compliance with vehicle requirement 2.3 in the Statement of Work, all parachute systems in the vehicle were designed and manufactured by the team. Precession in assembly of the recovery subsystem was crucial in contributing to flight reliability and confidence. The team-designed parachutes were carefully sown with nylon thread. Rather than being attached to grummets, the shock cords were sown into the seams of the parachute such that they converge to the center. This design allows the shock cords to have many points of contact with the parachute so that the forces distribute properly. A proper technique was established and tested for the folding and packing of all parachutes with their accompanying harnesses. In addition, all separation charges were tested statically prior to test flights. Further detail regarding construction methods and recovery testing can be found in the recovery subsystem section of the design review.

Test Data and Analysis

Airframe Staging

During the flight of Project Lambda, the booster section will separate from the main bay via a black powder charge 0.47 seconds after the main motor burns out. The black powder charge is located on the top bulkhead in the coupler that connects the booster section and the main bay. Testing was conducted to determine exactly how much black powder was required to ensure the separation occurs without damaging the rocket in any way.

To determine the amount of black powder required, the following equation was used: Amount of black powder (g) = (diameter of compartment in inches)^2 x (length of compartment in inches)^2 x 0.006. As the diameter of the compartment is 6 inches, and the length of the compartment is 2.25 inches, the total amount of black powder needed was calculated to be 1.35 g.

After construction, the rocket was laid on the rocket stand, and a ¾ inch PVC cap was filled with 1.35 g black powder. Unlike usual black powder charges, the PVC cap was inverted, and small holes drilled through the side. This was done so that when the black powder charge ignites to over pressurize the compartment, there is no chance of it also igniting the sustainer motor, which is located directly above the coupler.

An igniter was inserted, and the booster section and main bay were connected. Two shear pins were also inserted. At this point, the team performed a safety check to ensure the area was clear, and that no hazardous substances were located anywhere near the rocket. After the all clear, the black powder charge was ignited. The rocket separated instantly and successfully, without damaging the interior in any way.

During the first full scale flight, the team yet again used 1.35 g of black powder for the airframe separation. The booster section and main bay separated exactly as predicted in flight, without excessive force. The rocket was not damaged whatsoever by the black powder charge. Further details on the results of the full scale flight can be found under full scale launch test results.

Component Testing

Table 2: Component Test Data

Location	Component or Subsystem	Test Type	Purpose	Results	Details	Status
Mini Avionics Bay	Component: Raven3 accelerometer	Static Ground Test	To determine proper accelerometer calibration to ensure data collected is accurate.	Live data from the accelerometer was 0.83 axial G's.	Live data determined by manufacturer should be .8-1.2 axial G's to ensure properly calibrated.	Successful
Mini Avionics Bay	Subsystem: LVIS- Raven3	Static Ground Test	To ensure proper functionality of Raven3 with use of a flight simulation.	Flight simulation was successful without anomalies.	The Raven3 flight simulation was completed using the manufacturer's flight profile software. The flight simulation showed that the Raven3 was properly functioning.	Successful
Mini Avionics Bay	Component: Raven3 Barometer	Functional Ground Test	To ensure barometric pressure sensor functions properly for deployment of booster parachute.	Raven3 worked as planned	Tested using a bell jar with an LED in the pyro pin of the Raven3 and programmed to send a current if the barometric pressure within the bell jar is between	Successful
Mini Avionics Bay	Component: Raven3 Timer	Functional Full-scale Flight	To ensure that the stages separate at two seconds using flight logic	Stages separated at two seconds as planned.	Tested using the full-scale flight time>2secs.	Successful

Location	Component or Subsystem	Test Type	Purpose	Results	Details	Status
Mini Avionics Bay	Subsystem: LVIS- Raven3	Functional Full-scale Flight	To ensure flight logic was properly programmed for stage separation and parachute ejection.	Parachute deployed at designated altitude using flight logic.	The pressure increasing and the altitude greater than 512ft.	Successful
SMART Bay	Component: Raven3 accelerometer	Static Ground Test	To determine proper accelerometer calibration to ensure data collected is accurate.	Live data from the accelerometer was 0.95 axial G's.	Live data determined by manufacturer should be .8-1.2 axial G's to ensure properly calibrated.	Successful
SMART Bay	Subsystem: LVIS- Raven3	Static Ground Test	To ensure proper functionality of Raven3 with use of a flight simulation.	Flight simulation was successful without anomalies.	The Raven3 flight simulation was completed using the manufacturer's flight profile software. The flight simulation showed that the Raven3 was properly functioning.	Successful
SMART Bay	Component: Raven3 Timer	Static Ground Test	To ensure that the charge is sent to the pyro pin at the designated time of 2.5seconds	Ground test confirmed, timer lit the LED at 2.5 seconds.	Jerk test was performed to simulate a launch and the Raven3 was set to send current to the pyro pin connected to an LED at 2.5 seconds. Current approximately 1.9 Amps	Successful

Location	Component or Subsystem	Test Type	Purpose	Results	Details	Status
SMART Bay	Component: RockeTiltometer	Static Ground Test	To ensure proper circuitry of component.	Ground test confirmed circuitry properly connected as the series three beeps showed no anomalies.	Circuitry was set up as specified by manufacturer and throughout the system's checks; the system had three beeps which confirms that the circuitry was properly connected.	Successful
SMART Bay	Component: RockeTiltometer	Static Ground Test	To ensure ignition battery switch functions properly.	Ground test showed that once switched on, the battery was functioning properly by the two beeps heard.	The ignition battery switch was turned on and the beeping changed to only two beeps. This confirms in the user manual that the ignition battery switch functions properly.	Successful
SMART Bay	Component: RockeTiltometer	Static Ground Test	To ensure that the ignition arming switch functions properly	Ground test showed one switched on, the ignition arming switch functioned properly by the sound of one beep.	The ignition arming switch was turned on and the beeping changed from two to one beep. This confirms that the system is properly armed as stated in the user manual.	Successful
SMART Bay	Component: RockeTiltometer	Static Ground Test	To ensure igniter will ignite within critical angle.	Ground test confirmed that the igniter would light if angle of attack is within the critical angle	Tested using a 6 volt light bulb and simulated launch conditions.	Successful

Location	Component or Subsystem	Test Type	Purpose	Results	Details	Status
SMART Bay	Component: RockeTiltometer	Static Ground Test	To ensure igniter will not light if outside of the critical angle.	RockeTiltometer2 did not send current to the light bulb after the component was outside of the critical angle.	The component was allowed to dynamically calibrate in a vertical condition, next a manual launch was triggered and the RockeTiltometer was put outside of the critical angle and the ignition signal was sent but no light appeared as expected.	Successful
Avionics Bay	Subsystem: LVIS- Raven3	Static Ground Test	To ensure proper functionality of Raven3 with use of a flight simulation.	Flight simulation was successful without anomalies.	The Raven3 flight simulation was completed using the manufacturer's flight profile software. The flight simulation showed that the Raven3 was properly functioning.	Successful
Avionics Bay	Component: Raven3 Barometer	Functional Ground Test	To ensure barometric pressure sensor functions properly for deployment of the drogue and main parachutes.	Raven3 barometer detected change in pressure	Tested using a bell jar with an LED in the pyro pin of the Raven3 and programmed to send a current if the barometric pressure within the bell jar is between	Successful

Location	Component or Subsystem	Test Type	Purpose	Results	Details	Status
Avionics Bay	Component: RRC2 mini Barometer	Functional Ground Test	To ensure barometric pressure sensor functions properly for deployment of the drogue and main parachutes.	RRC2 mini barometer detected change in pressure	Tested using a bell jar with an LED in the pyro pin of the RRC2mini and programmed to send a current if the barometric pressure within the bell jar is between	Successful

Workmanship
The precision that is involved with this project is undoubtedly high. In order to enable mission success, everything that is completed must be done as best as possible. The team values its work, and puts all its efforts into doing a proficient job. In designing the rocket, simulations were carefully examined to ensure that the rocket performed safely and efficiently. When building the full-scale rocket, the team understands that everything must be precisely manufactured for the flight to follow the predictions of the models as well as those of the subscale flight.

The team is taking every necessary precaution to ensure that the rocket is constructed properly. Before construction began, the team researched the best possible methods of construction. Then, those who wanted to make the components practiced using the tools needed. The rest of the team determined that the work was up to standard before that person was allowed to proceed to manufacturing.

The team wants the rocket to function exactly as planned. The rocket must reach the intended height, the separations must occur at the times that have been decided, the recovery systems must deploy properly – every phase of construction must be done right in order for the rocket to perform the way it is supposed to. The team intends to keep a close eye on the construction and assembly of every piece in order to ensure that everything can be assembled correctly and functions properly.

Safety and Failure Analysis
The following chart is a standard risk matrix used to identify and rate risks in this project. This risk matrix utilizes a 1 to 5 scale for both the severity and likelihood of each, where 1 is trivial or remote, and 5 is fatal or certain. Risks are ranked by the product of its two scores. The risks are also color coded by risk level where green requires little to no mitigations, yellow requires some mitigations for the success of the project, and red is absolutely critical for the team to be successful. This method of ranking is used for all tables with a "Risk Level" column throughout the FRR. Numbers in parentheses under "Risk Level" is a reevaluated level after significant mitigation is done to a medium or high risk.

Likelihood

Severity	1 Remote	2 Unlikely	3 Possible	4 Likely	5 Certain
1 Trivial	1	2	3	4	5
2 Minor	2	4	6	8	10
3 Lost time	3	6	9	12	15
4 Major	4	8	12	16	20
5 Fatal	5	10	15	20	25

Figure 16: Risk Matrix Chart

Table 3: Safety and Failure Analysis

Risk	Causes	Consequence	Mitigation Strategy	Risk Level
Vehicle Testing Failure	Poor launch day procedures, poor overall rocket design, failure of ignition and recovery electronics.	Damage to parts, vehicle, or payloads. Falling far behind the timeline because of the need to rebuild. Replacement parts do not fit into the budget.	Rigorous tests at a system and subsystem level. All static testing is to be completed before test launches. A backup rocket body of the same dimensions in the event the airframe is damaged beyond use.	16 (9)
Testing Delays (weather or issues at the launch site)	Inclement weather, failure to secure FAA waiver.	Falling behind projected timeline or inability to test launch by deadline.	Multiple launch sites available to use (FAR, Lucerne Valley, Santa Fe Dam) Have contacts at each of the nearby launch sites or clubs. Plan multiple potential test dates early to avoid bad weather.	6 (4)
Failure of Electronics (non-recovery)	Poor programming, usage of drained or depleted batteries, poor handling of electronics causing a short.	Failure to retrieve data and reduction to the overall science value of the project.	Multiple tests of all electronics. The CubeSat, voltmeter, hazard detection, recovery electronics, and scoring altimeter are all on separate circuits. Also, in order to work on the electronics in the rocket a member of the team had to pass several trials demonstrating proper technique and electronics safety to minimize failure due to construction.	16 (12)
Failure of Electronics (recovery)	Poor programming of avionics, poor wiring to battery, avionics not correctly secured on payload sleds.	Failure of main or drogue parachutes.	Use of altimeters with built-in redundancy, that have passed ground tests. Launch with avionics that have been flown in test launches and retested to ensure functionality.	5
Failure of scoring altimeter	Poor wiring to battery, avionics not correctly secured on payload sleds.	Failure to report altitude and failure to score.	Test scoring altimeter and fly it in test launch before competition. Housed in the center of the avionics bay on its own circuit to minimize any effect by other components, motors, or parachute deployments.	5

Risk	Causes	Consequence	Mitigation Strategy	Risk Level
Battery low/failure	Use of drained or depleted batteries, use of batteries with excessive output.	Recovery electronics cannot deploy parachutes, payloads cannot collect data and lose scientific value.	Appropriate large capacity batteries are used for payloads to provide power longer than flight and time on launch pad. Always use a new battery for altimeters. Checklist has the safety officer and one other member check all batteries.	4
Hazards During Transportation and Handling of Motors or Black Powder	Unsafe procedures, smoking near explosive materials.	Damage to motor resulting in unusable motor, failure to launch, injury and burns.	Motors and black powder is only handled by certified members with the ok of the safety officer. Both will be transported and stored by the team mentor or safety officer only. No smoking within 25 feet of any flammable or explosive materials.	5
Availability of Parts	Damage to current parts, complex design requiring more custom parts.	Delay or stop construction of rocket or payloads. There is also a risk of buying cheaper parts that are not ideal for the overall plan of the rocket.	Design of the main rocket has constantly been in progress and changes are always checked to ensure the needed parts are available before they are finalized.	3
Shipping delays/missing parts	Budget constraints can't afford expedited shipping	Delay to vehicle or payload construction and testing. Failure to meet timeline.	All parts are ordered early to ensure they arrive before they are needed. Extra body materials are ordered to accommodate for missing parts and changes to design.	4
Access to required tools.	Specialized tool is required.	Delays in the fabrication of vehicle parts, failure to meet timeline.	General construction was completed at team members' houses where a safe work area was available. More specialized construction such as laser cutting or welding was done at either the schools automotive department or at a local build shop with appropriate tools.	1

Risk	Causes	Consequence	Mitigation Strategy	Risk Level
Access to sufficient workspace or machine shop	Faculty at the schools automotive department is not available to open the shop. School is closed.	Delay in fabrication, failure to meet timeline	General construction was completed at team members' houses where a safe work area was available. More specialized construction such as laser cutting or welding was done at either the schools automotive department or at a local build shop with appropriate tools. Build up a professional relationship with local shops for our team and future teams.	1
Personnel Shortage	Health concerns, time constraints, personal issues, job offer.	Loss of momentum in the build process, increase in workload or remaining members resulting in a decrease in workmanship.	Strong communication between team members and advisors. No part of the project is understood by only one team member so all parts are still covered in the absence of a team member.	1
Failure to maintain budget	Insufficient fundraising efforts, poor overall design requiring expensive components, repair costs of failed flight.	Lower quality of parts reducing the overall quality of the rocket and its safety factors.	The budget is regularly checked during meetings and managed by the faculty advisor. Work hard as a team to follow all mitigations to prevent need for repairs.	4

Full Scale Launch Results

First Test Flight

Figure 17: Project Lambda on the Launch Pad

On Sunday, April 13th 2014, the team conducted a full scale test launch of Project Lambda at Lucerne Valley. The primary purpose of the launch was to verify that the rocket meets every single requirement specified in the SOW, and also to determine how the actual flight compared to the subscale and the simulations performed prior to the full scale launch.

Figure 18: The Rocket Owls and Project Lambda

Wind speeds were between 5 mph and 10 mph at ground level. The rocket was assembled and readied for launch in a little over an hour. None of the payloads were placed inside the rocket, meaning the only avionics on board were the Raven3 altimeters.

The first stage of the flight was immensely successful. The booster section separated after main motor burnout, just as planned, and the recovery system deployed when the booster section reached its own apogee at 850 ft. AGL. The booster section was successfully recovered with no damage whatsoever to the rocket or the components inside.

Unfortunately, the main motor did not ignite as planned following the detachment of the booster section. This was not because of any fault in programming the Raven3, but rather due to insufficient current provided by the battery. This will be resolved by using a lithium ion battery that will provide more current, enough for sustainer ignition.

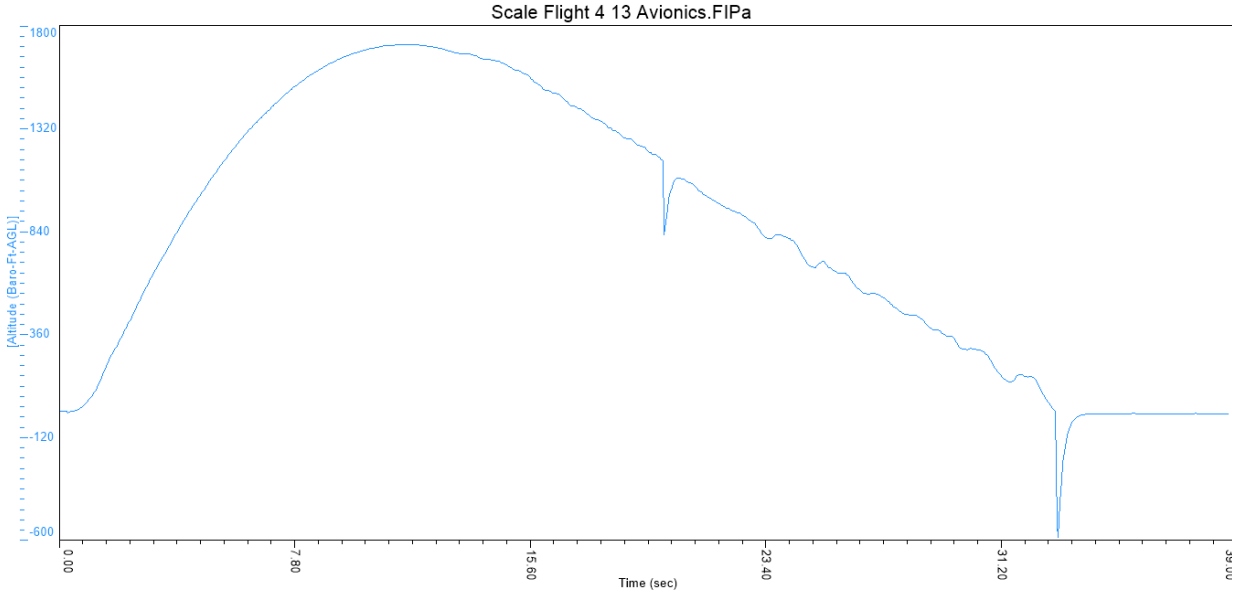
This by itself would not have affected the recovery of the rocket body, as the drogue parachute was set to deploy at 2500 ft., and the main parachute was set to deploy at 1200 ft., if the sustainer did not ignite. However, since the rocket reached apogee at 1717 ft. AGL, it never reached the height required to deploy the drogue parachute. As for the main parachute, although the rocket body separated to allow the main parachute to unfurl, the shock cord had gotten tangled, preventing the parachute from deploying. As a result, the rocket landed with excessive kinetic energy, and thus suffered damage to its airframe. However, none of the electronics or components inside the rocket were damaged in any way, and almost everything except a section of the body tube was salvageable.

The results of this flight were essential in helping the team recognize areas of the project that need improvement – for example, packing the parachute properly in launch day procedures. However, the flight also demonstrated that if the team can improve in this area and use a better battery, the rocket is aerodynamically sound and should be able to successfully and safely conduct a multistage flight.

To verify this fact beyond a doubt, the team intends to conduct a second full scale launch on Sunday, April 20th, 2014. This time, the team will take precautions to pack the shock cord correctly, and to use a battery that provides enough current to ignite the sustainer.

Figure 19 below shows the barometric altitude data gathered by the Raven3 in the avionics bay, which will act as the official scoring altimeter.

Figure 19: First Full Scale Flight Altitude Data from Avionics Bay Raven3



The rocket reached apogee at 1717 ft. AGL about 12 seconds into flight. The two downward spikes seen on the graph can be attributed to two events: first, the black powder charge that separated the rocket airframe for the deployment of the main parachute at 1200 ft. AGL; and second, the rocket body landing on the ground.

When compared to the flight profile simulation generated by RockSim, which can be found in the flight profile simulation section under mission performance predictions in this report, it becomes apparent that the apogee is much lower than intended. This is largely due to the fact that the sustainer motor did not ignite, throwing off the expected values.

Second Test Flight

On Sunday, April 20th 2014, the team conducted a second full scale test flight of Project Lambda. Based on the results from the first test flight, there were two main objectives for this flight: to ensure that all parachutes deploy so the rocket is successfully recovered, and to ensure the sustainer motor is capable of being airstarted.

With these two goals in mind, the launch day procedures heavily focused on proper packing of the parachute. Each parachute was folded carefully, and after being placed inside the rocket, the fit of each parachute was manually tested to ensure a reasonably small amount of force could easily pull out the parachute. The parachute was then repacked, and the shock cord was neatly gathered and folded into S-folds with a single piece of masking tape holding the folds together. This was done to ensure the parachute's shock cord could not get tangled and prevent the parachute from coming out of the rocket.

In our first full scale flight, the rocket's sustainer motor did not airstart. The team hypothesized that this was due to insufficient current from the battery. To fix this, the team used a 9 volt lithium ion battery that was tested and determined to provide enough current to light the igniter.

The launch was conducted under ideal conditions, with minimal wind or cloud cover. Just like the previous launch, the main motor ignited, the booster section separated, and the booster parachute deployed exactly as planned. Data from the Raven3 altimeter in the booster section places apogee for the booster section at about 825 ft AGL.

At this point, the sustainer was supposed to ignite, but the sustainer never ignited. The rocket simply reached apogee at 1363 ft. AGL, and began descent back to earth. Unlike the first launch, both parachutes deployed, but it appeared that the main parachute and the drogue parachute deployed simultaneously, even though the drogue was supposed to deploy at apogee and the main at 1200 ft. Nevertheless, the entire rocket was safely recovered with no damage done to any of the payloads or electronics onboard.

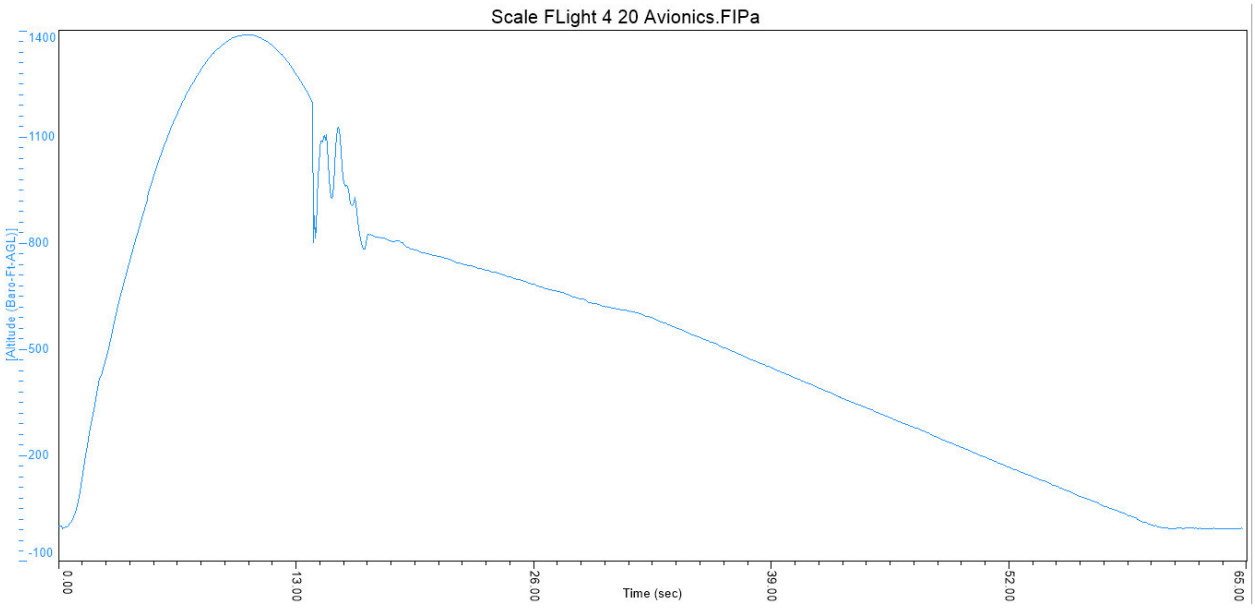
Post-flight analysis showed that the sustainer's e-match had indeed lit, but had failed to ignite the sustainer. This indicates that during the launch of the rocket, the e-match had fallen away from the igniter pellet, which was why the sustainer did not ignite. To prevent this, the team will conduct a third full scale flight, where the sustainer's e-match will be taped around a wooden dowel that will guide the e-match into the igniter pellet to ensure the e-match lights the sustainer.

As for the simultaneous deployment of the two parachutes, at first the main hypothesis was that the pressure from the black powder charge was causing the Raven3 altimeter's barometric pressure sensor to detect a lower altitude than it really was, and thus deploying the main parachute a little too early. To remedy this, the team decided to use gorilla tape to seal up the gaps between the bays, so the overpressurization of one compartment could not affect the Raven3.

After analyzing the Raven3 altimeter, however, it became apparent that the simultaneous deployment of the two parachutes was actually due to a programming error – the altimeter was mistakenly set to deploy the main parachute after velocity exceeded 4 ft/s downward. This has been corrected, and the Raven3 has been double checked to ensure the correct programming is in use for the third subscale flight.

Figure 20 below shows the barometric altitude data gathered by the Raven3 in the avionics bay.

Figure 20: Second Full Scale Flight Altitude Data from Avionics Bay Raven3



Again, this data differs greatly from the simulations generated by RockSim, in large part because the sustainer still did not ignite. The dramatic peaks and fluctuation in pressure around 1200 ft. AGL are due to the black powder charges that deployed the main and the drogue parachute around the same time.

Third Test Flight

On Sunday, April 27th 2014, the team conducted a third full-scale test launch of Project Lambda at Lucerne Valley. This was the last possible day for the rocket to have a successful launch and thus allow the Rocket Owls to continue in the NASA Student Launch competition. The team originally planned to launch on Saturday; however, the weather conditions on Saturday were too extreme to permit a launch – wind speeds were upwards of 50 mph, and the weather forecast also predicted rain. Thus, the team made the decision to launch on Sunday instead. The weather on Sunday was mild compared to Saturday, but still, wind speeds varied, with the wind growing

stronger throughout the day. Nonetheless, the team worked around the weather conditions and attempted to launch as early as possible to have the most favorable conditions possible.

The primary purpose of the launch was to verify that the rocket meets every single requirement specified in the SOW, and also to ensure the team has devised a proper method for ignition of the sustainer motor.

At the time of launch, wind speeds were roughly about 15mph-18mph. The rocket was assembled and readied for launch in a little over an hour. The Tesseract payload was integrated in the vehicle, along with the RockeTiltometer, which was set to inhibit the charge of sustainer motor ignition if the vehicle's flight trajectory was 40 degrees off from vertical, and official and redundant altimeters (Raven3 and RRC2 Mini) were also integrated during flight.

Both flight stages of the vehicle were extremely successful. During the first flight stage the booster section separated after main motor burnout, just as planned, and its parachute deployed successfully. During the second flight stage, the sustainer motor ignited properly, and the drogue parachute deployed successfully at apogee, which was at 4996 ft. AGL. The main parachute also deployed successfully and the vehicle was recovered upon landing.

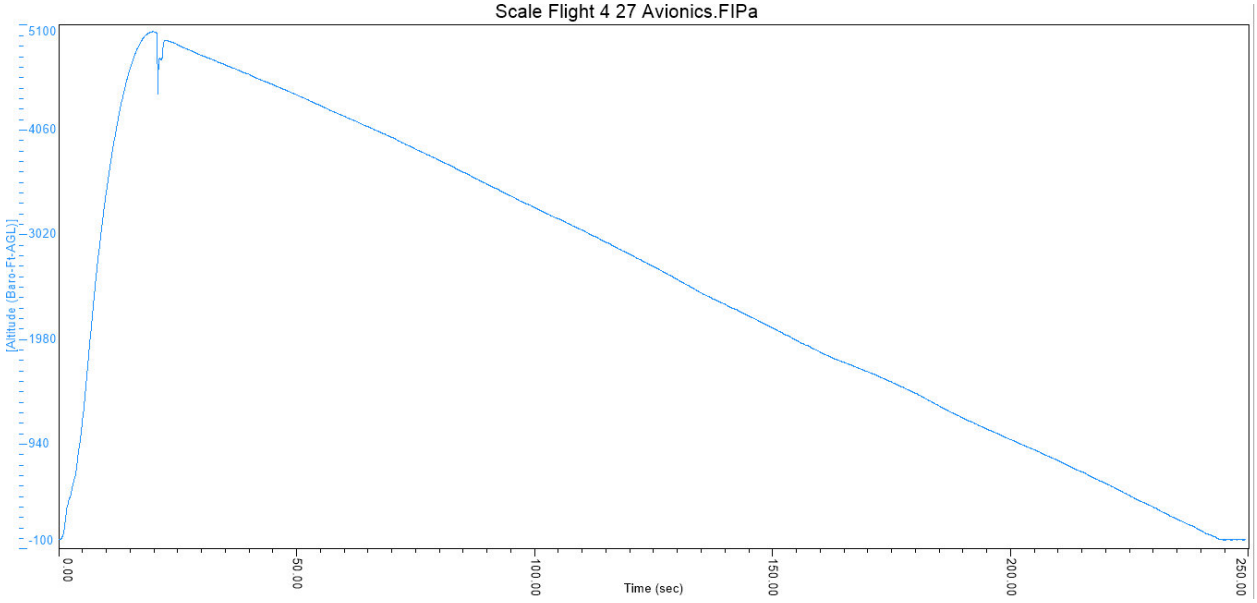
Unfortunately, upon recovering the vehicle, the team found the airframe of the second stage of the vehicle sustained damaged due to ziplining. The recovery harness for the drogue and main parachutes ripped through the airframe of the vehicle. This occurred because upon takeoff winds pushed against the fin section of the rocket causing the vehicle to weather cock and deviate from a perfect, vertical flight trajectory. Upon sustainer ignition, the data from the RockeTiltometer indicated the vehicle's trajectory to be 22 degrees off from vertical, which was still in range. However, because the rocket now had a ballistic flight trajectory, the vehicle started losing altitude and pressure at high speeds. When the altimeter deployed the parachutes, the vehicle was still at relatively high speeds horizontally, causing a high force load to be applied to the parachute. In turn, this caused the recovery harness to shred through the airframe. The vehicle's booster section along with all internal components of the vehicle remained intact and in perfect condition.

The results of this flight demonstrate the successful events and stability of Project Lambda's flight trajectory. Without high winds present, Project Lambda would have displayed an exceptional and stable flight performance. However, since that day, April 27, 2014 was the last day to qualify for the competition, the team deemed it necessary to proceed with the flight of Project Lambda even under unfavorable weather conditions.

Given the opportunity to proceed in the competition, the team is ready to repair all damages to the airframe of the second stage, and have it ready to launch by competition.

Figure 21 below shows the barometric altitude data gathered by the Raven3 in the avionics bay.

Figure 21: Third Full Scale Flight Altitude Data from Avionics Bay Raven3

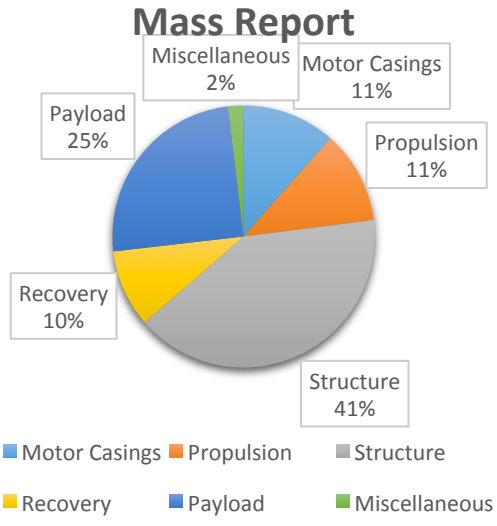


The data generated from the third flight is extremely close to the flight profile simulations generated by RockSim – the closest out of all three test launches. The apogee reached is still about 2000 ft. short of the predicted apogee. This, however, is due to the relatively strong wind speeds that pushed the rocket's trajectory about 22 degrees off the vertical, thus preventing the rocket from attaining its maximum height. Under calmer conditions, the rocket would have matched the simulations generated.

Mass Report

Figure 22 below shows the mass distribution of the launch vehicle, initially determined by RockSim values, and then adjusted to fit actual measured values.

Figure 22: Mass Distribution Chart



2. Recovery Subsystem

Robustness of Recovery System.

Structural Elements

The recovery harnesses used in the vehicle will be constructed of 1 inch tubular nylon webbing rated for 4000 lbs. of tensile force. The drogue harness will be 20 ft. in length, the main will be 30 ft. in length, and the booster will be 10 ft. in length. Each of these shock cords will be insulated from hot ejection charges by a Nomex sleeve located in front of the parachute, followed by a Nomex square to protect the parachutes. Additionally, each shock cord will be attached to its corresponding parachute by 5/16-inch quicklinks, which have a safe working load of 1,760 lbs. of force. Respectively, the shock cords will be attached to 3/8 inch U-bolts with a working load limit of 1090 lbs. of force. These U-bolts will be attached to 1 inch bulkheads constructed out of birch Plywood.

There will be three attachment points on each recovery system and the attachment procedure are detailed as follows. First, a U-bolt will be screwed and secured with epoxy onto a 1 inch bulkhead. The recovery harness will then be attached to the described bulkhead using a figure 8 follow through knot, and with a normal figure 8 knot below it, to ensure the knot does not unravel itself during the rockets recovery. Once the knots have been completed, the recovery harness will be fitted with a Nomex sleeve, to protect the shock cord, and a Nomex square will follow, to protect the parachute from ejection charges. Second, another figure 8 follow through knot will be tied 2/3 of the way up from the first attachment point. This precaution is made to guarantee that the rocket bodies will not collide during their descent. Then, the loop made from the knot will be inserted into the quicklink, in addition to the parachute itself. Finally, the third attachment point will be manufactured in a similar fashion as the first; however, it will not be a Nomex sleeve or square, as it has been deemed unnecessary, and would require excess room in the rocket body, which the team cannot spare.

Electrical Elements

The electrical elements of the recovery system are the same as those of the entire vehicle. The details of the electrical elements can be found in the electrical elements segment of the design and construction of the vehicle.

Redundancy Features

The redundancy features of the recovery system include backup black powder deployment charges for both the drogue and main parachutes connected to a redundant altimeter. The redundancy features have been selected with the utmost consideration for a safe landing/ recovery in mind. The second altimeter that will be utilized is an RRC2 mini which was used previously, in last year's USLI competition. The redundant altimeter has been programmed with flight logic and tested statically using a bell jar with a vacuum to alter the pressure and simulate an increase pressure similar to that within the recovery of the landing. Throughout the last year's competition and testing this year, it proved itself extremely effective at detecting changes in barometric pressure, as well as its ability to send a current to the igniter which was statically tested using an LED in place of an igniter. The drogue and main bays, each have two PVC caps containing the same amount of black powder, one for redundancy, with 4.32g and 3.45g

respectively. The Raven3 altimeter located in the avionics bay has been programmed to send a charge to the first PVC containing black powder for deployment of the drogue at apogee which will be detected using the factory calibrated barometer with an additional condition that the rocket is above 1504 ft. This condition was set in the event that the sustainer motor does not light; the rocket will still be recovered safely.

Also, the redundant PVC in the drogue bay connected to the RRC2 mini has the same flight logic, with the addition of a two second delay. The estimated amount of distance at which the rocket may fall within the two seconds is 66ft not including air resistance. Thus, keeping the height requirement of 1504 ft. AGL is more than sufficient as the full scale launch went an altitude of approximately 1700ft AGL. Furthermore, the atmospheric pressure exposed to the redundant altimeter is the same as that of the primary altimeter, ensuring the deployment charges occur as programmed.

The flight logic programmed for the main parachute also uses the barometric sensors and the height requirement is less than 1216ft AGL. In addition, the RRC2mini is programmed with the same flight logic with the addition of a two second delay. Finally, though the redundant altimeter has proven itself effective in previous flights, ground testing and static testing, the team will functionally flight tested as the redundant altimeter on the weekend of April 19-20.

Parachute Sizes and Descent Rates

The following table summarizes parachute dimensions, vehicle masses, descent rates, and kinetic energies.

Table 4: Parachute Sizes, Mass of Sections, Descent Rates, and Kinetic Energies

Parachute	Parachute Size	Vehicle Section	Mass of Section	Descent Rate	Kinetic Energy
Booster	60 inches	Booster Section	6 lbs	22.6 ft/s	50 ft.-lbs
		Mini Avionics Bay	3 lbs	22.6 ft/s	24 ft.-lbs
Drogue	85 inches	Drogue & Main Bay	29.5 lbs	54 ft/s	--
		Drogue Bay	11 lbs	17.5 ft/s	52.6 ft.-lbs
Main	120 inches	Avionics Bay	8 lbs	15 ft/s	28 ft.-lbs
		Main Section	8.5 lbs	15 ft/s	30 ft.-lbs

Drawings and Schematics of the Electrical and Structural Assemblies

The rocket will utilize a Raven3 altimeter as the official scoring altimeter, as well as an RRC2 mini altimeter for the required redundant altimeter. Each altimeter will obtain its own 9 volt lithium battery, and be wired independently of one another, to guarantee this redundancy. Raven3 altimeters will be deploying the main and drogue parachutes. The Raven3 will set off an ejection charge which will separate the booster section for the parachute to eject. Another Raven3 will be used to eject the booster parachute. Figures 4 and 5 show the electrical schematics for the Raven3 altimeters and the RRC2 Mini.

The Raven3 altimeters will be connected to black powder charges inside of each of the bays. The connection scheme for the parachutes can be found in Figure 24. (pg. 37)

Figure 23: Seperation of Rocket Sections with Shock Cord Attachment

Figure 23 shows how the sections of the vehicle will separate. It also shows where the shock cord will be attached for the parachute. There are five separate sections that will be recovered through three parachutes. The leftmost shock cord will hold the drogue parachute. The middle shock cord will hold the main parachute and the rightmost shock cord will hold an additional parachute to recover the booster section. The Raven3 in the avionics bay, which is between the drogue and main parachute, will ignite black powder charges to deploy both parachutes.

Rocket-Locating Transmitters

Within the body of the vehicle, three different transmitters will be used in order to locate the three sections of the rocket that will separate. After the booster burns out, the booster section will separate from the rest of the rocket so that the sustainer can ignite. The booster section will have its own GPS to track its location for recovery. The next GPS will be housed in the avionics/ camera bay. This section of the rocket, as well as the sustainer section, will detach from the drogue bay and nose cone after the main parachute deploys. The last GPS will be housed in the drogue bay, specifically within the CubeSat.

The GPS within the Avionics/ Camera Bay will be the Adafruit Ultimate GPS. This GPS runs on a frequency of L1 (1575.42 MHz), and will be connected to the Raspberry Pi Module. The GPS data will be sent to the ground through an XBee wireless transceiver. This transceiver will be programmed to communicate with an XBee connected to the hazard detection ground station through XCTU.

The GPS within the CubeSat and the Drogue Bay will be the EM 406-A Sirf III. The Arduino Mega microcontroller will be operating this GPS unit and runs on the L1 (1575.42 MHz) frequency. The data from this device will be transmitted to the ground station through an XBee wireless transceiver. This transceiver will be programmed to communicate with an XBee connected to the Tesseract ground station using XCTU.

The GPS that will be housed within the Booster will be the RoamEO GPS. This GPS is a standalone device that will transmit the data that it acquires to a dedicated receiver. The data will be sent through radio frequencies. The receiver will determine the distance from the GPS to the receiver as well as the direction that the signal is coming from.

Sensitivity of Recovery System to Onboard Devices

The recovery systems of the rocket include the Raven3 microcontrollers, the RoamEO GPS, the EM 406-A, the Adafruit Ultimate GPS, and the XBee transceivers. In the nose cone, the XBee transceiver has been tested in close proximity of the EM 406-A GPS. The XBee transceivers worked properly and the GPS unit still collected data with a fair amount of accuracy. During launch, the recovery system for the nose cone is expected to work properly since no signal interruption was seen in this test. The hazard detection system makes use of the same transceiver and antenna to transmit data. This system will employ the Adafruit Ultimate GPS for recovery. Based on the test from the CubeSat system, the Adafruit Ultimate GPS is predicted to operate without any problems. However, testing will be performed soon to support this prediction. The RoamEO GPS uses transmitters and receivers for locating. This device is not in close proximity with any other recovery systems and will not threaten any device related to the recovery of the vehicle.

Suitable Parachute Size

The diameter of each parachute was determined by the equation:

$$D = \sqrt{\frac{8mg}{\rho C_d v^2 \pi}}$$

where D is the diameter of the parachute, g is the acceleration due to gravity, ρ is the air density, C_d is the coefficient of drag of the parachute shape, and v is the terminal velocity. This equation can also be rearranged to determine the velocity of the rocket, when determining how much kinetic energy the rocket lands with.

Figure 24 below details the actual attachment scheme of the recovery system. Each end of the recovery harness will be attached to one inch bulkheads, to ensure that each attachment point has a sufficient capability to withstand the forces of the ejection charges.

Figure 24: Recovery Attachment Scheme

Each parachute will be deployed with the primary use of a Raven3 altimeter. The Raven3 altimeters will be connected to switches on the body of the rocket, and will not be turned on until the rocket is ready for launch. Also, they will be connected to a black powder charge placed on the attached bulkhead. For the booster parachute, the Raven3 has been programed to deploy its parachute when the booster section achieves its own apogee, pressure increasing and altitude above 512 ft. AGL. For the drogue parachute, the next Raven3 has been programmed to deploy the parachute when the sustainer section reaches apogee, pressure increasing and altitude above 2528 AGL. However, during the test flight, since the sustainer motor did not ignite, the rocket was unable to reach an altitude of at least 2528, and the drogue parachute was unable to deploy. Due to this finding, the team has determined to program the Raven3 to deploy the drogue parachute when pressure is increasing and the rocket has reached an altitude of at least 1504 ft. Finally, the main parachute, with the same Raven3 altimeter as the drogue, has been programmed to deploy the main parachute when pressure is increasing and when the rocket has reached 1216 ft. Both the drogue and main parachutes will also have separate ejection charges connected to the RRC2 mini altimeter for redundancy, with the same flight logic plus a 2 second delay. Each altitude was determined by multiples of 32, due to the Raven3 altimeter's limitations.

For static testing of the ejection charge, the team has determined to use these amounts of black powder: 3.80g for the booster parachute, 4.32g for the main parachute, and 3.45g for the drogue parachute. Each component separated as planned; however, for the main parachute, the parachute was not wrapped fully and completely with the Nomex blanket, and got singed slightly. The main parachute has been repaired following this incident, and will be packed into the body tube more efficiently for future flights.

During the test flight, the booster section had a perfect flight; therefore, the team has decided to keep the same flight logic and amount of black powder. Since the sustainer did not light, the rocket was unable to reach an altitude of at least 2528 ft. After analyzing the test flight data, the rocket reached apogee of 1700 ft., so the team has come to a consensus and change the flight logic of the altimeter from 2528 ft. to 1504 ft. The amount of black powder will remain the same for the drogue. For the main parachute, the flight logic and amount of black powder will also remain the same, but the team will ensure that all components of the recovery system are placed within the rocket carefully, so that the parachute will deploy properly.

Safety and Failure Analysis

The safety and failure analysis of the recovery system is included with the main vehicle safety section.

3. Mission Performance Predictions

Mission Performance Criteria

Project Lambda's mission will be deemed successful if and only if it meets the following criteria during launch:

- Separation of stages occurs safely
- The booster section of the rocket detaches safely from the main rocket body without forcing the rocket off-course
- The booster section parachute deploys when the booster section reaches its own apogee
- The sustainer motor is airstarted by the Raven3 without swaying the rocket off-course
- The Raven3 records measurable data on the vibrations produced during the burning of the 98mm motor as opposed to the vibrations produced during the burning of the 54mm motor.
- The nose cone conducts enough triboelectric charge to alter electromagnetic waves being emitted from the CubeSat near and at apogee
- The ground station is able to identify these alterations
- The Hazard Detection System relays the images and hazards to a ground station in real time
- The rocket must be safe and stable before, during, and after its flight
- The rocket must reach an altitude of 7000 ft. AGL, give or take 50 ft.
- The drogue parachute will deploy at apogee
- Upon reaching 1200 ft. AGL, the main parachute will deploy
- Each rocket component, tethered and untethered, will land with a kinetic energy of 75 ft.-lbs or less

Flight Profile Simulations

Figure 25 below shows the flight profile simulation as generated by RockSim.

Figure 25: Flight Profile Simulation

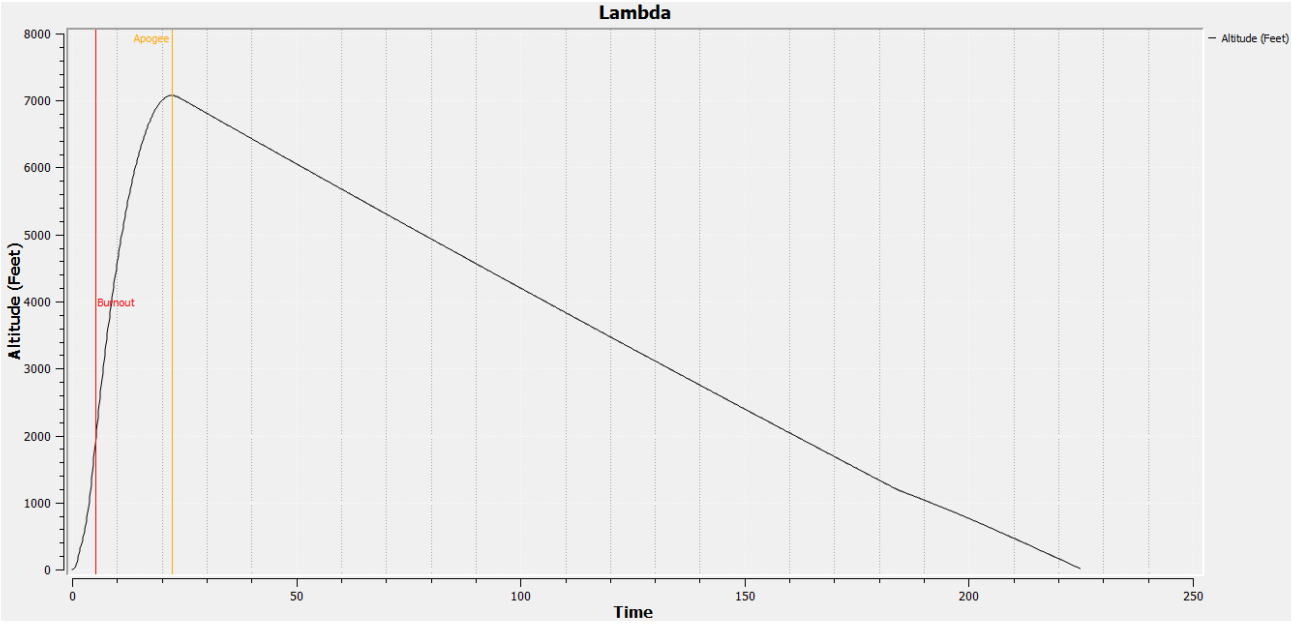


Figure 26 below show the altitude recorded by the Raven3 in the avionics bay, which is our official scoring altimeter. This altitude is much lower than that determined by RockSim, because the sustainer did not ignite during flight.

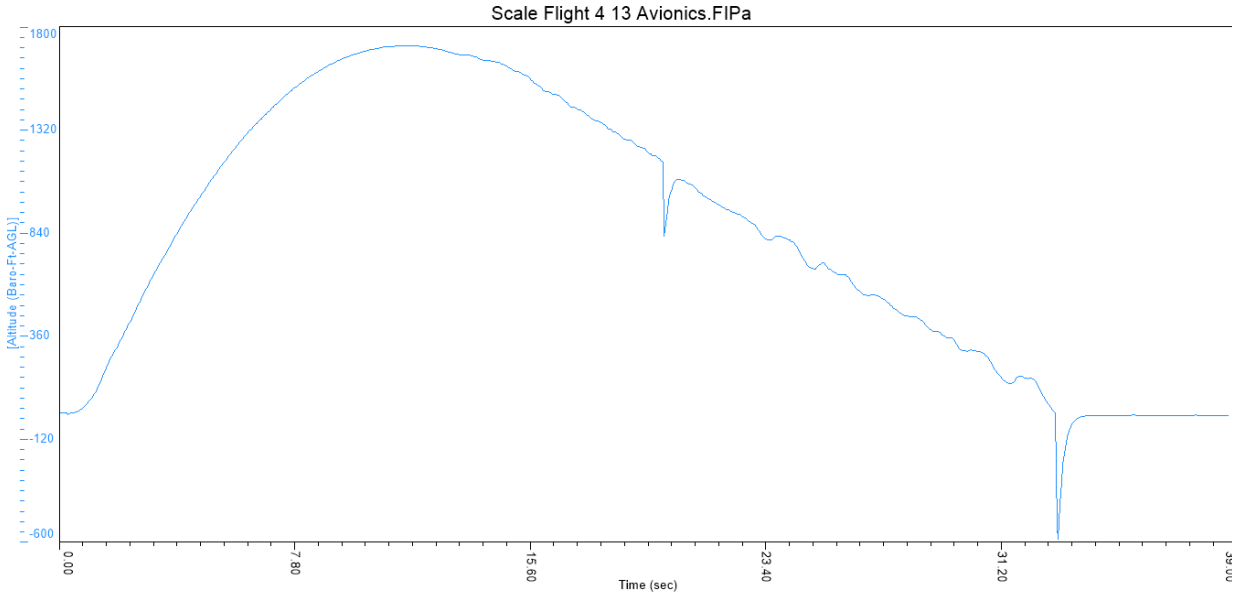


Figure 26: Actual Flight Data

Figure 27 below is the thrust curve of the main motor, a Cesaroni K1620-Vmax.

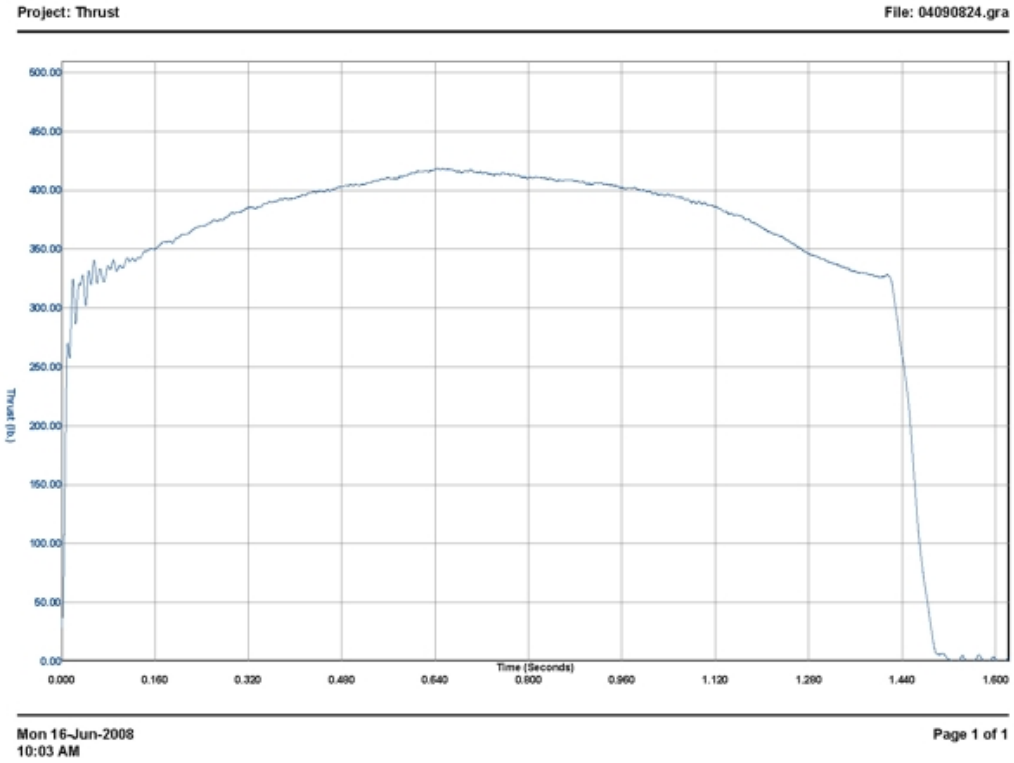
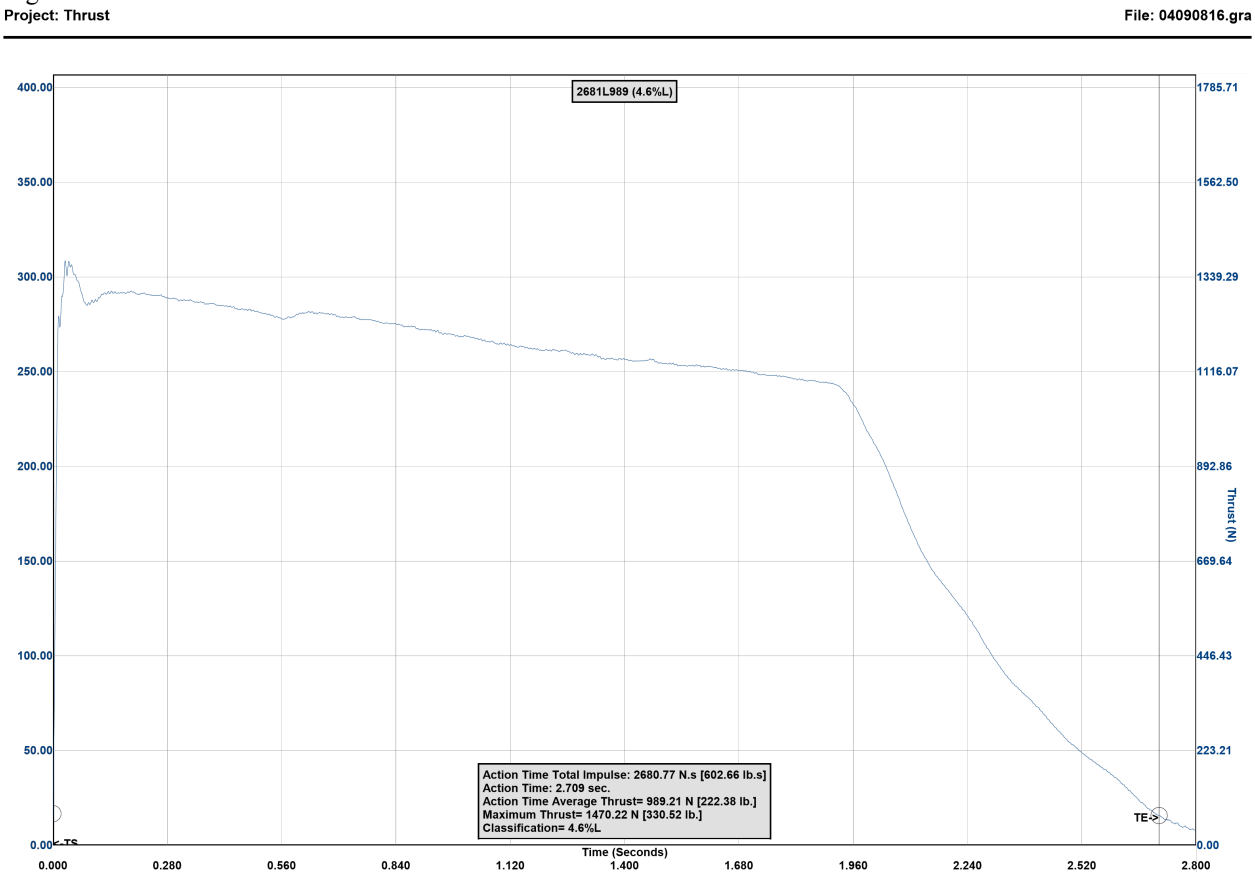


Figure 27: Cesaroni K1620-Vmax Thrust Curve

Figure 28 below shows the thrust curve of the sustainer motor, a Cesaroni L985 TT.

Figure 28: Cesaroni L985TT Thrust Curve



Thoroughness and Validity of Analysis

The proper design and construction of the vehicle is essential to the team's success. In the designing process, the team used different resources, including the team mentor, to ensure that the proposed design was strong enough structurally to withstand the conditions that the rocket is going to endure.

During the rockets construction, multiple team members inspected each component as it was being manufactured. Once manufacturing of a component was completed, the piece was test fitted to ensure that the dimensions were correct. Small changes were made where necessary. The team took note of these changes, so that the simulations could be altered if needed.

During analysis of the recovery systems, the weights of the different sections of the rockets were double checked with the predicted weights. If the weight of the sections weren't close to the predicted weights, RockSim was used to determine the impact velocity of that independent section and calculations were performed to determine if the kinetic energy was still within the required limit of 75 ft.-lbs.

The drag analysis was done using the graph of the coefficient of drag that RockSim had simulated for the rocket. RockSim gave us the coefficient of drag for the overall rocket, as well

as specific sections of the rocket. The drag on the rocket was determined at specific points throughout the rockets flight. The coefficient of drag was taken from the overall coefficient of drag that the graph provides. The main concern was with the stresses on the rocket. The team wanted to ensure that the body could withstand the forces that would be applied on the surface of the rocket.

All the data from the full scale test flight was analyzed and compared with simulations. First, the simulations were adjusted to model the mass more accurately. Then, the velocities and altitudes were compared and the difference in actual and simulated values were determined. The error in the simulations was noted, and this knowledge was applied to our predictions of how the actual flight would perform. The team wants to be sure that the flight characteristics are known as accurately as possible to adjust the payload and vehicle components correctly.

Drag Assessment

The following figure shows the coefficient of drag for the various sections of the rocket, as well as the rocket as a whole. This coefficient is plotted against the altitude of the rocket.

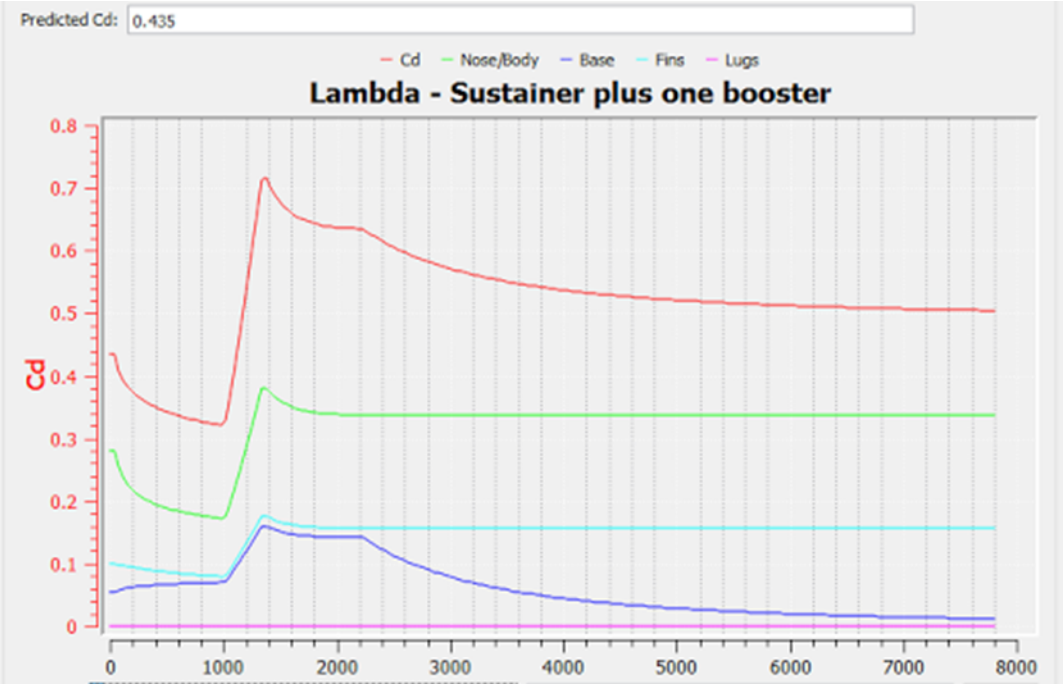


Figure 29: Project Lambda Coefficient of Drag

Using the graph of the coefficient of drag, the force of drag was determined for different points in the booster and sustainer flight. The coefficient of drag graph that is shown in red was used to determine drag for the different points. This was determined using the drag equation:

$$D = C_d \frac{\rho V^2}{2} A$$

where D is the force of drag, C_d is the coefficient of drag, ρ is the air density, V is the velocity, and A is the reference area. With the booster, the rocket will travel at a max speed of V ft/s and the coefficient of drag ranges from about 0.34 to 0.44 for this stage of the rocket. For the second

stage of the rocket, the booster will fall off and the coefficient of drag will change. The velocity will reach a max of V ft/s and the coefficient of drag increases to around to 0.7 and decreases as the flight continues. This creates a much larger force due to drag since the V-max has a much larger thrust than the previous motors. The full scale test flight was used as a basis to determine whether the drag would have negative effects on the vehicle and none were found so fat.

Scale Modeling Results

Project Lambda has currently undergone one test flight and has another test flight planned for Saturday, April 19th. The first test flight was deemed unsuccessful due to a malfunction in two areas.

The booster section performed flawlessly and successfully showed that the vehicle was capable of a stable flight. The booster ejected at the intended time and the parachute opened properly. However, a lack of current from the batteries that were used to power the Raven3 caused the igniter for the sustainer to fail to ignite. Since the sustainer did not light, the rocket reached apogee much too early. The drogue parachute was programmed to eject under the conditions that the vehicle had reached apogee and the vehicle was at least 6000 ft. AGL. Since the second condition was never met, the drogue never ejected.

However, the ejection charge for the main did go off. Unfortunately, due to an error in the packing of the shock cord, the parachute never came out of the rocket even though the section separated. The shock cord got stuck in the rocket when it tangled behind the parachute. Everything above the sustainer came crashing to the ground. The sustainer and avionics bay was completely destroyed and the nose cone and drogue bay were fairly damaged.

Data from the flight has been discussed in the full scale flight section. The team has a new rocket ready for flight and has made the necessary adjustments for a successful flight. It was found that the predicted altitude that the booster was supposed to bring the rocket to was higher than the actual altitude that was recorded by the Raven3. The mass of the rocket was higher than the predicted value and adjustments have been made to the simulations to determine if the mass played a role in the difference in simulated and actual altitude. It turned out that these adjustments brought the predictions much closer to the actual flight data. The next test flight will be used to verify these predictions and more adjustments will be made if necessary.

Stability Margin

Table 5 below shows the center of gravity and pressure of both stages of the launch vehicle. Figures 30 and 31 demonstrate these values. The blue dot represents the center of gravity and the red dot represents the center of pressure.

Table 5: Stability Margin

Stability Margin			
	Stability Margin	Center of Gravity	Center of Pressure
With Booster	1.68	87.6 in	98.0 in
Without Booster	1.14	65.8 in	72.8 in

Figure 30: CG and CP with Booster Section

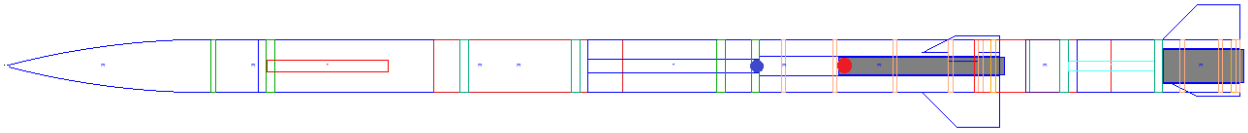
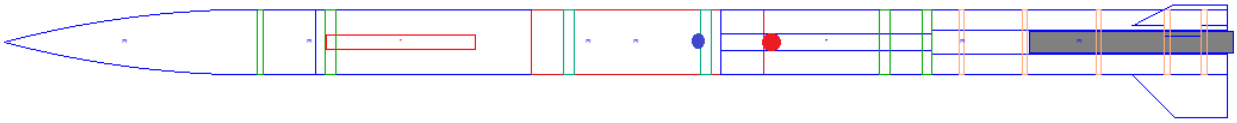


Figure 31: CG and CP without Booster Section



Kinetic Energy

The kinetic energies for each section of the launch vehicle can be found on Table 4.

Launch Vehicle Altitude and Drift Calculations

Table 6 below shows how far from the launch pad the rocket body will land. These values were determined by RockSim, and will be compared with the values of the test launch.

Table 6: Drift Table

Drift Table					
	0 mph	5 mph	10 mph	15 mph	20 mph
Range	0 ft.	1050 ft.	2284 ft.	3654 ft.	4515 ft.
Altitude	7089 ft.	7078 ft.	7043 ft.	6981 ft.	6888 ft.

4. Verification (Vehicle)

Table 7: Requirements and Verification

#	Vehicle Requirement	Design Feature	Verification	Status	Details
1.1.1	The target altitude shall not exceed 20,000 feet above ground level.	The selected motors will allow the rocket to reach a maximum altitude of 7000 ft. AGL.	Rocket Simulation program / Full scale test flight	Complete	Flight simulations project apogee at 7000 ft. AGL/ Full scale test flight with just the booster motor reached apogee at approximately 1700 ft. AGL. This is less than the simulated prediction, which ensures that the final launch altitude will be less than 20,000 ft.
1.2	The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in the competition scoring	The avionics bay is equipped with a Raven3 altimeter which contains an extremely accurate barometric altimeter as the main scoring altimeter, and an additional RRC2 mini barometric altimeter included for redundancy.	Pressure test / Subscale test flight/ Full scale test flight	Complete	The altimeters have passed ground pressure tests using a pressure changing bell jar and a light source to act as an igniter and have previously been tested in flight during last year's USLI competition. Additionally the team has tested the primary altimeter during the subscale and first full scale launch. The second full scale launch shall carry both altimeters.
1.2.1	The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after competition flight.	Both the Raven3 and RRC2 mini altimeters report altitude via a series of beeps.	Subscale test flight/ Full scale flight test	Complete	Both altimeters have been tested in flight. The altitude was communicated via a series of beeps.

#	Vehicle Requirement	Design Feature	Verification	Status	Details
1.2.2.3	At the launch field, to aid in determination of the vehicle's apogee, all audible electronics, except for the official altitude-determining altimeter shall be capable of being turned off.	All audible electronics will contain a switch which will be turned off after landing. Additionally, both altimeters have external switches so that one can be turned off after landing.	Full scale test	Complete	During the first full scale test, only the Raven3 reported the altitude via a series of beeps. During the second full scale launch, the team will use both altimeters and switch the redundant in the off position to ensure that the only audible device is the Raven3.
1.3	The launch vehicle shall be designed to be recoverable and reusable.	All rocket components, other than those pertaining to black powder charges, are designed to be recoverable and reusable.	Subscale test flight	Complete	Subscale was successfully launched and recovered without damage to any of its components
1.4	The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.	Hatches and detachable bulkheads were included in project design to assist in ease of payload and airframe assembly on launch site.	Scale test flight/ Full scale	Complete	The launch vehicle was prepared for flight within 2 hours for both the subscale and the full scale launches.

#	Vehicle Requirement	Design Feature	Verification	Status	Details
1.5	The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.	In selecting electrical components for rocket subsystems, storage space and battery lifetime were critically considered. Computer programming will assist in minimizing redundant data.	Subscale test flight/ Full scale test flight	Complete	Subscale model was successfully launched and fully functional subsequent to remaining on the launch pad in launch-ready configuration for 1 hour, as timed by team members. The Raven3 altimeters and the RockeTiltometer2 are capable of remaining on for two hours with a new 9 volt lithium battery.
1.6	The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.	The igniter used to ignite the main motor will be capable of burning with a standard 12 volt DC firing system.	Ground / Subscale Test/ Full scale Test	Complete	Subscale model and full scale rocket successfully launched with cold standard 12 volt DC firing system.
1.8	The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).	All motors being used in test and competition flights are commercially available ammonium perchlorate composite propellant.	Researched	Complete	Motors have been purchased from Animal Motor works which is a commercial retailer of APCP rocket motors.

#	Vehicle Requirement	Design Feature	Verification	Status	Details
1.10	All teams shall successfully launch and recover their full scale rocket prior to FRR in its final flight configuration.	A test date for the full scale rocket has been con scheduled for April 4.	Full scale flight	In progress	The first full scale launch confirmed that the booster section is completely flight ready. A second full scale test will be completed on 4/19 or 4/20 to confirm the entire rocket is in its final flight configuration.
-	The team will need to incorporate a fail-safe system into the sustainer to prevent sustainer ignition if the trajectory is off nominal	The vehicle will contain an ignition control system which monitors the tilt of the rocket and inhibits the sustainer from igniting if outside of the critical angle.	Ground / Full scale test flight	In progress	A ground test was conducted to ensure that the RockeTiltometer2 is able to safely airstart the sustainer within the accepted range. Testing has concluded that the RockeTiltometer2 is successfully able to detect a tilt angle and to inhibit the igniter if outside of the critical angle.

5. Safety and Environment (Vehicle)

Safety Officer

Joshua will act as safety officer for the Rocket Owls. He is TRA - Level 1 certified, and has training in emergency medical treatment and hazmat response. As the safety officer, Joshua will be responsible for providing technical leadership for the safety, quality and mission assurance in the construction and launch of Project Lambda and other activities conducted by the Rocket Owls. These responsibilities include the direct oversight of the team during manufacturing when safety is of concern, as well as the independent assessment of the rocket's safety. To fulfill those responsibilities the safety officer will ensure that all team members have access to and have read relevant safety rules for all equipment and materials they are using while enforcing safe practices while building and at the launch site. Other responsibilities include: maintaining MSDS reports and having them on hand for all used material and ensure the proper use and storage of chemicals and motors.

Analysis of the Failure Modes, Payload Integration, and Launch Operations

The 5 greatest risks based on the risk matrix are discussed in the table below. Likelihood and Severity values have been adjusted to reflect completed and ongoing mitigations.

Table 8: Greatest Vehicle Risks

Risk	Likelihood (1-5)	Severity (1-5)	Consequences	Mitigations
Failure to Eject Main Parachute	2 - Packing a parachute can leave a lot of room for human error. This failure occurred during a test launch and	4 - While the drogue should slow down the rocket slightly, once the detachable bulkhead is released the main body of the rocket will fall with no parachute. Despite the strength of construction, damage of a crash will still be significant.	The rocket body will take extreme damage. Payloads can receive high damage as well. Without the recovery of the rocket the mission is not successful and most of the experimental data will be lost.	To prevent the likelihood of this happening again the recovery specialist has done research on proper packing techniques and will be the only one to pack the parachutes. This process will be supervised by the safety officer. This will reduce the likelihood of human error to cause deployment failure. The main bay will also be cleared of protuberance within the bay to prevent the parachute and shock cord from being caught. The body of the rocket is also constructed from Blue Tube 2.0 and the fins are fiber glassed tip to tip to better withstand some damage. The severity value was not reduced however as we saw during a failed test launch, the rocket body will still be highly damaged in the event of a crash.
Parachute Lines Tangle	2 - Parachute lines can be easily tanged if proper packing technique is not followed.	4 - This is rated as such for the same reasons as "Failure to Eject Main Parachute" is rated. The damage if this was too occur would be great.	If the lines of the parachutes tangle the rocket will fall at with much higher kinetic energy than allowed with a high possibility of extreme damage to the rocket.	This hazard also relies on proper packing procedures to mitigate the likelihood of it occurring. As long as the procedures for packing the parachute are followed any error in packing should be caught before launch.

Risk	Likelihood (1-5)	Severity (1-5)	Consequences	Mitigations
Failure of Electronics (non-recovery)	3 - This failure is very broad and relies on many components all working flawlessly. As it is so all encompassing, the likelihood of it occurring is still high despite mitigations.	4 - In the event that non-recovery electronics fail there is the possibility of the loss of all experimental data.	If experimental data is lost the rocket holds very little scientific value.	Each electronic component is tested and each system and subsystem have their own hazard mitigations that help prevent an overall failure.
Vehicle Testing Failure	3 - Vehicle testing is a mandatory element of this project. .Only a small failure in one systems or subsystems could cause the entire test to fail.	3- Damage to the rocket could be small or large in the event of a test launch failure. For this reason, a middle severity was decided.	Ranging from failure to meet timeline to extreme damage to the rocket, high stress on team members to make up for a failed test.	The vehicle body has been carefully designed and simulated on RockSim. Launch site procedures and checklist help to catch all mistakes before they become hazards.
Sustainer Motor Fires at Unacceptable Angle of Attack	1 - With the RockeTiltometer, all current from the altimeter for ignition will be blocked if the rocket has an angle of attack greater than 25 degrees.	5 - If someone were to be hit by a downward firing rocket it would result in a fatality.	If the sustainer were to fire at a large angle of attack it could thrust horizontally or it could hit someone. If the rocket thrusts horizontally, the rocket will land very far and will likely be unrecoverable. If the motor fires downwards towards an observing crowd it could result in a fatality.	The RockeTiltometer works much like a switch. If the angle of attack is greater than 25 degrees, then the ejection is set to off. No current will be allowed to pass through the igniter preventing any unsafe launches. If the angle of attack is within an acceptable degree the RockeTiltometer will switch to the on position and current will be allowed to pass through the circuit.

The various risks to the team and launch vehicle during a launch, the consequences of the risk, and the mitigation plan for each risk are outlined for the vehicle failure, propulsion failure, and recovery failure in Tables 9, 10, and 11 respectively.

Table 9: Vehicle Failure Modes

Risk	Cause	Consequence	Mitigation	Risk Level
Center of gravity is too far aft	Poor overall rocket design.	Under an acceptable stability for flight.	Room is left in the nose cone to add mass to the nose cone around the CubeSat.	3
Center of pressure is too far forward	Poor overall rocket design.	Under an acceptable stability for flight.	Proper simulation testing. Increase the size of the fins to lower the center of pressure.	3
Rail button failure	Rocket lifts off at an unacceptable/unsafe angle, rocket falls off, does not fit or is too tight on the rail.	Rocket lifts off at an unacceptable/unsafe angle, rocket falls off the rail.	Check to see of the rail button fits on the launch rail pre-launch, sand the button if it fits too tight on the rail, replace with another button if it is too loose in the rail. Buttons screwed into rocket through the body tube and a centering ring.	2
Fin failure	Poor construction, damage during previous flights.	Unstable flight, further damage to the rocket.	A jig was laser cut to give precise placement of the fins to ensure there is a 120° separation between each fin, fully slotted and given ample time for epoxy to cure. Fins are further strengthened with fiberglass running from tip to tip for all fins. Fins will be checked over after every flight and any repairs will be made before the	6 (2)
Shearing of airframe	Forces on the rocket on sections damaged in previous flights.	Loss of rocket.	Blue Tube 2.0 was selected for the body tubes and couplers for strength. Rocket is checked for damage after every flight.	3
Premature rocket separation	Poor programming of altimeters. None or too few shear pins placed at separation points.	Failure to reach target altitude, failure of recovery system.	Follow checklist to see if the shear pins are secure before launch, test the timers in test launches, calculated black powder charges.	2

Risk	Cause	Consequence	Mitigation	Risk Level
Centering ring failure	Cracks in centering rings from previous flights, not enough epoxy on the centering rings.	Reduced stability, damage to payloads.	Check construction of centering for a good fit, check for damage to centering rings pre and post launch.	2
Bulkhead failure	Not enough epoxy for bulkheads that are epoxied in, not enough length left on the all thread allowing the wing nuts to be pulled off.	Damage to payload, avionics, failure of recovery.	Proper construction, extensive ground testing of removable bulkheads.	2
Failure of Detachable Bulkhead to Detach (vehicle hazard only)	Not enough black powder to separate the tether.	Nose cone and drogue bay remain connected to the main body of the vehicle during descent. Total kinetic energy on landing should be unaffected.	Significant testing of appropriate black powder to separate the tether holding the bulkhead in with and without load.	6 (3)
Early Separation of Detachable Bulkhead.	Poor programming of altimeter that ignites the black powder in the tether. Failure of quicklinks to hold the tether together.	Increase in velocity on main vehicle between drogue and main deployment. Potential zippering of the airframe.	Load testing of the quicklinks connecting the two bulkheads and static testing of the recovery system.	8 (4)
Nose cone failure	Separation of nose cone during flight, nose cone cracks due to previous damage	Under an acceptable stability for flight, damage to payload, unable to relaunch rocket.	The nose cone is constructed from fiberglass painted in conductive paint. The nose cone will always be inspected after every launch.	4

Table 10: Propulsion Failure Modes

Risk	Causes	Consequence	Mitigation	Risk Level
Total Motor Ignition Failure	Faulty motors, failure of igniters, failure of ignition equipment.	Failure to launch, unstable flight, or change in trajectory.	Redundant igniters, proper motor assembly.	1
Motor Ignition Failure due to Igniter Falling Out.	Improper setup of rocket on launch pad, igniter not fully inserted into the motor	Failure to launch, unstable flight, or change in trajectory.	High heat foil tape to hold igniters securely in place.	1
Motor igniter not reaching the end of the motor.	Insertion of the igniter without the use of an insertion tube.	Prevention of complete motor burnout or lack of motor ignition influencing the trajectory of the rocket.	The igniters will be marked with a permanent marker at the length of the motor. Igniters will also be inserted using an insertion tube to allow pushing the igniter all the way in without damaging it.	1
Exploding of the motor during ignition	Missing O-ring, faulty motor, failure in motor handling.	Loss of motor casing, loss of rocket.	Static testing of motors.	5
Motor mount failure	Not enough epoxy to hold the load bearing centering rings in place.	Motor launches into the body of the rocket, damage to payloads, loss of rocket	Proper construction and installation of the motor mount. The main and sustainer motors have a thrust plate.	4
Motor retention failure	Motor not assembled properly, retention bolt not fully screwed into the motor mount.	Motor falls out during launch	Both the ProX and Animal Works motor casings have built in motor retention systems that allow the motors to be easily bolted into the vehicle.	4
Motor thrust block failure	Motor launches into the rocket, damage to components and vehicle body.	Motor fires into the rocket body, damage to payloads, loss of rocket	Proper construction and installation of the thrust block.	4

Risk	Causes	Consequence	Mitigation	Risk Level
Premature burnout	Motor manufacturer's error, ignition causes the motor to burn irregularly (not from top to bottom).	Failure to reach target altitude	Static testing of motors.	2
Motor failure	Improper motor storage, missing components in motor assembly.	Unstable flight, failure to reach target altitude, loss of motor casing	Assembly of motors by certified members only.	4
Sustainer motor fires at unacceptable angle of attack	High winds, launch rail at larger angles, poor aerodynamic design.	Failure to meet projected altitude, inability to recover rocket, danger to personnel on the ground.	Sustainer ignition is controlled by both the Raven3 altimeter and the RockeTiltometer. The Raven3 will send the ignition charge but this charge will be inhibited by the RockeTiltometer if the angle of attack is 25 degrees.	25 (5)

Table 11: Recovery Failure Modes

Risk	Cause	Consequence	Mitigation	Risk Level
Rapid Descent	Holes in parachute, poor manufacturing of parachutes.	Damage to airframe and payloads, loss of rocket	Redundant altimeters, verification testing of the recovery system, simulation to determine appropriate parachute size.	3
Slow Descent	Poor parachute design (parachute is too big).	Rocket drifts out of intended landing zone, loss of rocket	Redundant altimeters, verification testing of recovery system, simulation to determine appropriate parachute size.	2
Parachute separation	Shearing of the nylon cord or shock cord.	Loss of parachute, loss of rocket, extreme damage to rocket and all payloads	Strong retention system, load testing.	4

Risk	Cause	Consequence	Mitigation	Risk Level
Failure to eject drogue parachute	Poor programming of altimeter, not enough black powder to eject drogue, tangle in shock cord wedges between parachute and body tube wall blocking the parachute from ejecting.	Rocket decent velocity is too high, main parachute deployment causes zipper in airframe.	Tested altimeters, calculated amounts in black powder charges, static testing of the recovery system, and anti-zipper ball on the shock cord. Shock cord is carefully wrapped in an S pattern and taped with easily sharable tape just to prevent tangling and knotting.	4
Failure to eject main parachute	Poor programming of altimeter, not enough black powder to eject drogue, tangle in shock cord wedges between parachute and body tube wall blocking the parachute from ejecting.	Rocket landing kinetic energy is too high, severe damage to airframe and payloads.	Tested altimeters, calculated black powder charges, static testing of recovery system, test launches.	12 (8)
Failure of booster section parachute	Poor programming of altimeter, not enough black powder to eject drogue, tangle in shock cord wedges between parachute and body tube wall blocking the parachute from ejecting.	Kinetic energy on landing is too high for each section. Damage to booster	Tested altimeters, calculated black powder charges, static testing of recovery system,	8 (4)
Parachute melt	Nomex cloth does not cover the parachute during packing, the parachute is wrapped too narrow and allows flames from black powder charges to wrap around the Nomex cloth.	Damage to rocket, loss of parachute, rapid descent resulting in higher than maximum kinetic energy	Proper protection from ejection charges, ground testing of recovery system, parachute packing done by the recovery specialist only and signed off by the safety officer before launch.	6 (3)

Risk	Cause	Consequence	Mitigation	Risk Level
Parachute tear	Sharp edges in the parachute bays catch during deployment.	Damage to rocket, loss of parachute, rapid descent resulting in higher than maximum kinetic energy	Safety check the parachute for damage, clear parachute bays for any possible defects the parachute could catch, proper packing of the parachutes.	5
Parachute lines tangle	Parachute packed wrong.	Parachute packed improperly, lines snag on airframe, obstruction on parachute shroud lines.	Follow proper procedure for packing parachute, design inner airframe with minimal protuberances, inspect shroud lines and remove any potential hindrances.	16 (8)
Rocket fails to separate	Too many shear pins used, insufficient black powder, failure of avionics to ignite black powder.	Insufficient black powder charges	Conduct static ejection tests to verify the correct amount of black powder	4
Damage to the rocket body	Too much black powder, unsafe work during launch setup.	Ejection charges burn and/or damage airframe, unable to reuse rocket body	Provide only enough black powder to provide ejection charge to prevent air frame damage	2

Listing of Personnel Hazards and Safety Hazard Data
A thorough evaluation of the possible hazards associated with the vehicle has been made with respect to the user as well as the environment. The hazards associated with the vehicle involve the storage of flammable substances such as motors and black powder, as well as the igniters and adhesives. The material safety data sheets pertaining to every aspect of the vehicle have been compiled and thoroughly studied for all completed and planned construction. With the construction of the rocket complete many of the safety hazards involved with construction are no longer as much of a concern. However, minor alterations may be made after further test launches and all tool and material safety should still be considered by the entire team.

Launch Site Safety
Launch site safety is a primary concern now that the project is moving from the design and construction and into its final stages. Much of the remaining work will be done through test launches and launch day preparation. The team will continue to meet before each launch and hold prelaunch briefing lead by the team leader and safety officer. This briefing will focus on safety for the tools and materials required on launch day, as well as a reminder of the NAR Safety Code.

Before launch day, the team will receive training in hazard recognition and accident avoidance; on the day of the launch, the safety officer will perform a safety check on the motor, payload, and recovery subsystems. The team will conduct a safety briefing both before and after each launch where the recognized hazards will be discussed as well as methods for mitigation.

Certification
An individual must be certified by either the NAR or the TRA to purchase and use high-power rocket motors. This certification is designed to ensure that the high power motors are being used only for the purpose for which they were designed. Team member Chris (TRA#14610), and the team's mentor, Rick Maschek (TRA #11388), are TRA Certified Level II. The certified members of the team are aware of the risks of high-power rocketry and will help the safety officer ensure a safe launch environment.

Motor and Black Powder Handling and Storage
Project Lambda includes 2 motors, with the largest being an L-class, reloadable rocket motor. High-power rocket motors generally contain highly flammable substances such as black powder or ammonium perchlorate. Therefore, they are considered to be hazardous materials or explosives for shipment purposes by the US Department of Transportation (DOT). The team is aware of and will follow all DOT regulations concerning shipment of hazardous materials. These regulations are contained in the Code of Federal Regulations (CFR) Title 49, Parts 170-179 and specify that it is illegal to send rocket motors by commercial carriers or to carry them onto an airliner. NFPA 1127 Section 4.19 contains the storage requirements of motors over 62.5 grams. All high-power rocket motors, motor reloading kits, and pyrotechnic modules will be stored by the Citrus Physical Science department ensuring they are all at least 7.6 meters (25 feet) from smoking, open flames, and other sources of heat. These will only be transported by the safety officer or team mentor who will follow all state and local laws in the transportation of low explosives.

California Designation of Cargo Section 27903.
(a) Subject to Section 114765 of the Health and Safety Code, any vehicle transporting any explosive, blasting agent, flammable liquid, flammable solid, oxidizing material, corrosive, compressed gas, poison, radioactive material, or other hazardous materials, of the type and in quantities that require the display of placards or markings on the vehicle exterior by the United States Department of Transportation regulations (49 C.F.R., Parts 172, 173, and 177), shall display the placards and markings in the manner and under conditions prescribed by those regulations of the United States Department of Transportation. 62

(b) This section does not apply to the following:
(1) Any vehicle transporting not more than 20 pounds of smokeless powder or not more than five pounds of black sporting powder or any combination thereof. The Tripoli Rocketry Association and the National Association of Rocketry have adopted the National Fire Protection Association (NFPA) 1127 as their safety code for all rocket operations. A general knowledge of these codes will be required of all team members. All members of the team will demonstrate competence and knowledge in handling, storing, and using high-powered motors. These include all reloadable motors, regardless of power class, motors above the F-class, and those which use metallic casings.

Adhesive Safety
Construction requiring adhesives is currently complete for Project Lambda, however minor touch ups may be required after any test launches to repair damages. When uses adhesives, the team member will always wear gloves and work in a well-ventilated area. Curing adhesives like epoxy will also require a dust mask to help prevent the inhalation of any fumes.

Tool Safety
The construction is complete, so the use of power tools should now be at a minimum. In the event that an alteration requires power tools the safety guidelines will still be followed by the team. Each team member using a tool must still demonstrate how to appropriately use the tool in question and follow all required safety protocols. Detailed in Table 12 are the tools used in construction of the full scale rocket, their hazards, and risk mitigation.

Table 12: Tool Safety

Tool	Risk	Risk Mitigation
Table Saw	Eye or respiratory irritation, bodily harm.	The table saw does have an open blade that can be extremely dangerous if used carelessly. Another piece of wood was used to push the pieces to be cut across the table while keeping hands away from the blade. Proper use of guide rail on the table saw. Protective eyewear, instruction on how to safely use the tool, read the user's manual.

Tool	Risk	Risk Mitigation
Band Saw	Eye or respiratory irritation, bodily harm.	A small band saw meant for cutting through metal pipes and rods. Once the rod has been secured into the machine will take over and slowly push the blade down as it cuts through. This tool is very safe and does not require hands to be anywhere near the blade while it is moving. Protective eyewear, instruction on how to safely use the tool, read the user's manual.
Miter Saw	Eye or respiratory irritation, bodily harm.	Anyone using the miter saw must learn how to operate all the locks and rotations to properly position the blade so that it cuts at the angle needed. Always use the blade guard to prevent being cut on the open blade. Protective eyewear, instruction on how to safely use the tool, read the user's manual.
Jigsaw	Eye or respiratory irritation, bodily harm.	The jigsaw can shake a lot if the material being cut is not clamped down. When using the jigsaw, the correct blade for the material being cut. Protective eyewear, instruction on how to safely use the tool, read the user's manual.
Hacksaw	Bodily harm	Use a steady back and forth motion and clamp down the material that is being cut to prevent slipping. Eyewear, only cut things that are securely clamped down.
Belt Sander	Eye or respiratory irritation.	Correct placement of the belt, and sand so the belt pushes away. Protective eyewear and gloves.
Power drill	Eye or respiratory irritation, bodily harm.	Wear protective eyewear, instruction on how to safely use the tool, read the user's manual.
Solder Iron	Inhalation may cause pneumoconiosis, tin poisoning, or lung irritation.	Research soldering methods, always work with a wet cloth to wipe solder off the iron, work in a well-ventilated area under bright light.
Laser cutter	Irritation or damage to eye	Team members doing laser cutting will take a class at the local build shop before doing any cuts for the team.

Environmental Concerns

The team will keep all our work environments and launch sites free of trash and dispose of all waste safely and responsibly. With respect to the environment, the team has made efforts to recycle all the materials from the previous rocket owls and will continue to work efficiently without creating excess waste. Any materials that are disposed of will be checked to see if they can be thrown away normally or if it needs to be done through special methods or through specific channels.

Disposal of Batteries

Alkaline batteries can be safely disposed of with everyday waste. Never dispose of a battery in a fire because they can explode. Rechargeable batteries packs will be reused by labs at Citrus or by future Rocket Owls. In the event that they need to be disposed of it will be done through a local electronics recycling center.

Disposal of Rocket Motors

All used or misfired rocket motors will be disposed of by soaking them in water until the propellant grains fall apart. The materials used in the motors are not harmful to personnel or to the environment and are therefore safe to dispose of normally after being soaked.

Disposal of Adhesives

No adhesives will be disposed of through any drain. Disposal methods will be checked on a material by material basis.

Impact of Environment on the Rocket

Below is a table of risks and mitigations for the environment's effect on the rocket.

Table 13: Environmental Impact on the Rocket

Risk	Consequence	Mitigation	Risk Level
Rain	Cannot launch	Check the predicted weather often before launch day.	1
High temperature	Motor or black powder become very hot and might ignite.	Proper storage of motors and black powder, keep an eye on the weather to launch ideal conditions.	1
Below Freezing Temperatures	Freezing on motor, epoxy and other parts can become brittle if cold enough.	California is unlikely to experience extremely cold temperatures. The safety officer will check the weather before all launch days.	1
Bird Strike	The trajectory will be altered.	Only launch when the sky is clear of birds and planes.	2
Humidity	Motor can fail if it gets wet even if that water is from high humidity. Damage to electronics.	Motors will be carefully stored, and all electronics will not be left plugged into a battery for long periods of time in high humidity.	2

6. Payload Integration

Payload Integration

Hazard Detection

The vehicle's avionics and hazard detection system payload are integrated through a typically designed rocket electronics bay of extended length. This setup will be composed of a tube with a slightly smaller diameter than the main airframe of the vehicle which is nested inside and held in place by an attached section of the body tube. Upon firing the drogue ejection charge, the aft end of the bay will remain in the vehicle's airframe and act as a mounting point between the vehicle and drogue parachute. At the event time when the main parachute is deployed, the bay will be completely separated from the fore end of the vehicle via a detachable bulkhead and act as a mounting point between the sustainer section of the vehicle and main parachute. Accordingly, this will allow the bay to reorient itself so the scanning camera has a clear view of the landing surface. Due to the fact that this system is integrated with the vehicle's recovery system, it is simple, compact, reliable, and does not add additional steps to the assembly procedure.

The main component of the electronics/hazard detection payload bay of the rocket is a 22 inch long section of blue tube 2.0 with the following dimensions: 6 inch x 0.077 inch wall, which will be housed in a 14 inch portion of body tube, extending 4 inches on either side. This tube serves as the coupler tube for the vehicle and has reinforced bulkheads fixed on each end of an 11-1/4 inch stiffy tube, also constructed of blue tube 2.0. The aft end bulkhead of the avionics bay will secure the recovery harness for the main parachute and the fore end bulkhead will be attached to a recovery tether which also attaches to the detachable bulkhead. The detachable bulkhead will secure the recovery harness for the drogue parachute. The stiffy tube will be epoxied inside the coupler tube, 6 inches from the fore end of the avionics bay, and 4-3/4 inches from the aft end of the bay. This will allow the detachable bulkhead to sit flush with fore end of the bay and allow extra room in the aft end of the bay for the main parachute. External interfaces, such as arming switches, will be located on the 14 inch portion of airframe housing the e-bay, allowing the payload bay itself to slide easily into the fore and aft sections of the vehicle. Moreover, ½ inch long #2-56 nylon shear pins will be connected to the fore and aft coupling sections of the e-bay to prevent any premature separations during the vehicles ascent. The 11-1/4 inch internal portion of the payload bay has been divided into a 7 inch forward bay and a 4 inch aft bay, by a ¼ inch birch plywood bulkhead. The official scoring and redundant altimeters along with their corresponding power sources will be located in the aft bay, while the Raspberry Pi, camera, GPS, XBee, and their power sources will be located in the fore bay.

Blue tube 2.0 coupler was specifically selected due its compatibility with the Blue tube 2.0 airframe of the vehicle. The very small marginal gap of 0.03 inches between the outer diameter of the coupler and the inner diameter of the airframe requires very precise manufacturing, and therefore was ordered from the Blue tube manufacturer's themselves to mitigate any risks of payload integration. Likewise, special consideration has been given to the space inside the bay. Although space is limited and the bay will house several electronics for tracking, hazard detection, and deployment charges, all of the components have been carefully organized to fit properly inside the bay. In the aft bay, where the official scoring and redundant altimeters are housed, the altimeters will be mounted to the top portion of the ¼ inch payload sled, while the

lithium ion batteries powering them will be mounted on the underside of the sled. Similarly, in the fore bay, the Raspberry Pi, GPS, and XBee will be mounted to the top of the sled and the Anker battery pack will be mounted to the underside of the sled. The camera will be fixed to the outer portion of the securing bulkhead in order to acquire images to be processed for hazard detection. Lastly, in the interest of conserving space, cables/wires connecting payload components have been carefully minimized and secured. Figure 32 below shows the payload interface visual.

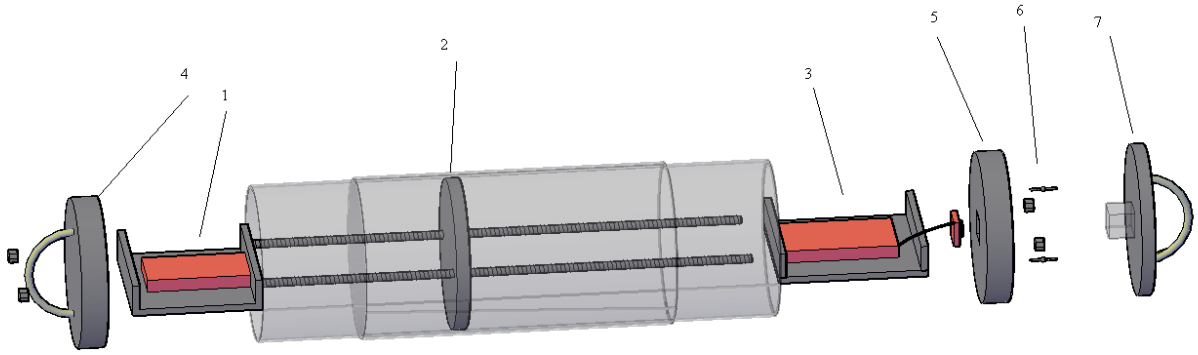
Figure 32: Hazard Detection Payload Interface Visual

The integrity of the avionics/hazard detection payload bay has been tested during the first full scale test flight. Although the flight was not considered a full success due to a malfunction in the recovery system, the internal payload bays remained intact. The vehicle flew stable in its first stage, however, it crash-landed and the 4 inch coupling portions of the payload bay sustained major damage. However, the internal payload bays did not sustain any damage to its structural elements, nor its electrical components. The vehicle was flown with altimeters and their power sources and were recovered undamaged and still functioning. In turn, the success of the first flight stage and the forceful impact of the bay upon landing, demonstrate the structural and housing integrity of the bay's capability to sustain forces acting on it during ascent as well as landing. Figure 33 displays the avionics/hazard detection payload bay layout, post-launch. The electrical components are not displayed to emphasize structural integrity.

Figure 33: Hazard Detection Payload Layout

The avionics/hazard detection payload bay utilizes a mechanically simple assembly procedure. The procedure is detailed as follows. First, the aft end of the bay is inserted 4-3/4 inches into the aft end of the coupler where it sits fixed on the stiffy tube and arming switches are then connected. Second, guide rails are placed on the protruding all threads and fore bulkhead is inserted 6 inches into the fore end of the bay where it sits fixed on the opposite of the stiffy tube. The fore avionics bay is then fastened with wing nuts and recovery tether is attached to a 3/8 inch forged eyebolt located on the fore bulkhead and detachable bulkhead via 1/8 inch 316 stainless quicklinks. The detachable bulkhead is then slid in the remaining free space of the fore end of the bay where it sits flush with the end of the 4 inch coupling section. Please note: all electrical components are fully wired and mounted to payload sleds prior to integration assembly. Lastly, the bay as a whole is inserted into the drogue and main bay of the vehicle, where it is fastened with ½ inch #2-56 nylon screws, acting as shear pins. Figure 34 below displays the components and assembly technique of the payload integration.

Figure 34: Hazard Detection Payload Assembly



LVIS

This payload is integrated very simply into the airframe of the vehicle through three bays – the mini avionics bay in the booster section, the Sustainer Motor and Raven3 Trigger (SMART) bay located directly above the sustainer, and the avionics bay above the main bay. Each bay will carry one Featherweight Raven3 altimeter, used both to trigger flight events and to collect data on lateral vibrations.

Once each Raven3 has been programmed, it is mounted to a 4 inch x 5 inch x 0.5 inch payload sled constructed out of birch plywood, using two small bolts, eight washers and two nuts, to keep it vertical throughout the flight. The Raven3 will be powered using a brand new 9 volt lithium ion battery attached to the payload sled using 4 small zip ties to keep the battery in place throughout the flight. Each payload sled is then slid into place inside its respective bay using the all threads that run through each bay.

Since the booster section must separate from the rest of the rocket, including the main avionics bay, after main motor burnout, it is necessary to incorporate a separate mini avionics bay into the booster section for parachute deployment. This mini avionics bay will contain a Raven3 microcontroller that will both control the separation of the booster section from the main bay and deploy the recovery system for the booster section, using the multiple programmable pyro channels and the barometric sensor. This Raven3 will also be recording the lateral acceleration experienced by the rocket throughout the flight, which will allow the team to cross reference the data collected during the burning of the main motor by the primary Raven3 in the avionics bay. The mini avionics bay is housed in a 4.5 inch stiffy tube bonded with epoxy to the inside of the 14 inch long coupler made out of blue tube. This coupler is adhered with epoxy to the body tube, and is accessible via a detachable bulkhead on the side facing the sustainer.

The Raven3 in the SMART bay above the sustainer has two functions: first, to ignite the sustainer, if the RockeTiltometer deems the angle of attach to be safe. Second, and most relevant to the LVIS payload, the Raven3 will record the lateral vibrations experienced throughout the flight of the rocket, during both the main motor stage and the sustainer stage. Although this is not the primary data collecting Raven3, the data collected by the Raven3 in the SMART bay will be used to double check and verify the data from the Raven3 in the avionics bay.

The Raven3 in the avionics bay is the official scoring altimeter, responsible for deploying both the drogue and the main parachutes. For the purposes of this payload, the lateral vibrations data collected by this Raven3 is also the primary data that will be analyzed post flight.

Tesseract

The triboelectric effect analysis payload has two subsystems that are housed in the nose cone and fore end of the drogue bay. The system is easily integrated through an arrangement of all threads, bulkheads, centering rings, nuts, wing nuts and washers. Beginning with the nose cone, a single all thread is centered and fixed into place inside the nose cone with epoxy. Two additional all threads measuring at 18.5 inches will be non-fixed and used along the side of the vehicle body to secure all the bulkheads and centering rings for the system. The nose cone bulkhead has a diameter of 5.8 inches and has three 0.25 inch holes along the diameter to allow the all threads to fit into place. One hole is exactly centered and the outer two holes are spaced 2.25 inches apart

from the center hole. The center hole is where the all thread from the nose cone will fit into place and the two outer holes are what will fit the non-fixed all threads.

The voltmeter subsystem is the first step in the assembly. It will be mounted onto a 5.5 inch by 3.5 inch electronic sled made from birch plywood. The electronic sled has two shelves extending along the 5.5 inch side, spaced 1.0 inch from one another. This will serve as the point of insertion for the all threads. Each shelf will extend 0.75 inches perpendicular to the sled. These shelves will have three 0.25 inch holes placed the exact distances as the previously described bulkhead for the nose cone. Once the voltmeter and its power source have been secured, the electronic sled will slide into the center all thread of the nose cone and the two outer all threads will slide in until the outer all threads extend 1.5 inches above the electronic sled. At this point a set of nuts will be placed on both sides of the shelves to secure the sled on top of the nose cone bulkhead. Once secured, the bulkhead will slide into the nose cone and the center all thread of the nose cone will fit into the center hole of the bulkhead. A washer and wing nut will then be placed to the bottom of the bulkhead to the all thread and secure the bulkhead inside the nose cone. Next is the placement of the CubeSat subsystem that will be housed in the aft end of the drogue bay, just below the nose cone bulkhead. Once the subsystem has been declared ready for launch, a bulkhead centering ring is placed on top of the CubeSat, and will slide into the outer all threads by two 0.25 inch holes spaced 4.5 inches apart along the diameter. It will be 6 inches in diameter and have a 4.33 inch x 4.33 inch square etched out in them to allow the CubeSat top side to fit into place. A set of washers and nuts will be added to both all threads to secure the bulkhead centering ring from moving during flight. A similar centering ring with the same dimensions except having the square from the center cut out, will be placed around the CubeSat through the all threads.

The Tesseract systems are housed in the nose cone and drogue bay. The CubeSat components will be housed in a chassis made out of 6061 aluminum with polycarbonate walls. The components will rest on polycarbonate sheets that slide into grooves in the aluminum walls. The shear strength of the aluminum used for the chassis is about 30000 psi and the polycarbonate has a shear strength of 9200 psi. The shearing strengths of the polycarbonate and the aluminum is much higher than the intended load experienced by the housing during launch. In the first test flight, the housing was put to a test that was never intended. The CubeSat chassis was implemented in this flight with mass simulators in place of electronics. Due to an error with shock cord packing, the parachute that would allow the safe recovery of the payload, did not deploy, and the section containing the chassis came crashing to the ground. However, upon investigation of the components within the nose cone and drogue bay, it was found that the CubeSat chassis was intact with no damage. It can be assured with great confidence that this component will be able to withstand the conditions of a successful flight and will hold the CubeSat electronics safely within it. The voltmeter electronics will be housed within the nose cone and will rest on a bulkhead and electronics sled. Both the bulkhead and electronics sled were made from birch plywood which also has a high shearing strength. The battery as well as the sensors and components of the voltmeter will be connected to the electronics sled and the Arduino will be connected to the bulkhead. This bulkhead and electronics sled will be mounted into the nose cone so that no movement of these components is possible. These bulkheads also survived the crash of the initial test flight and were deemed fit to hold the components safely throughout a successful flight.

Figure 35: Tesseract Payload Integration

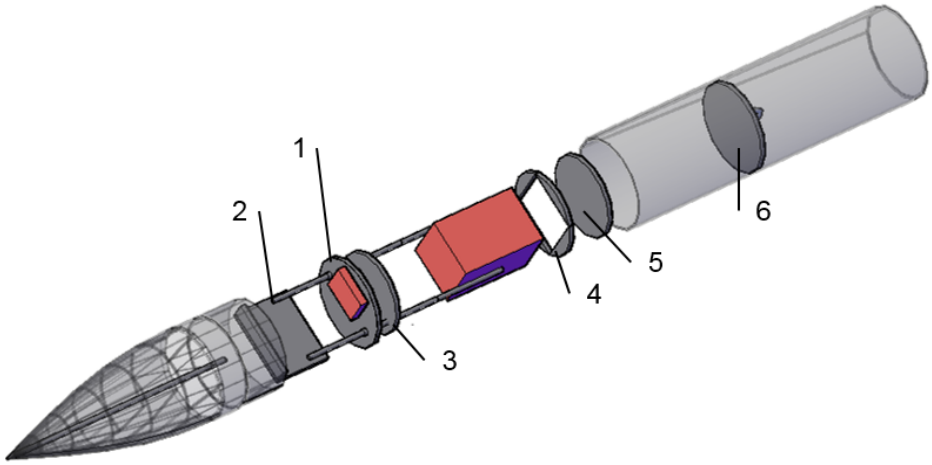


Figure 35 demonstrates the integration of the Tesseract payload into the vehicle. The red objects shown in the figure were made to represent the electronics of this payload. The integration of the payload starts with the electronics of the Voltmeter being attached to the electronics sled labeled two and the Arduino being attached to the bulkhead labeled one. Also, the components of the CubeSat will be attached to the shelves within the chassis. The bulkhead labeled one and the electronics sled labeled two will then start being mounted into the vehicle. Two all threads will slide into each of the outer holes on bulkhead one and will be locked into place with wing nuts on either side. The electronics sled will then slide onto the 3 inch side of the all threads and will be locked into place with regular nuts. This assembly will then slide into the nose cone so that the all thread slides through the center hole in both the bulkhead and the electronics sled. A wing nut will be screwed onto the center all thread which will prevent the assembly from being pulled down. Two wing nuts will be screwed on upside down at the other end of the all threads. The bulkhead labeled three will then be slid onto the all thread. This bulkhead has a square indentation to hold the CubeSat. Next, two regular nuts will be screwed onto the all threads and the centering ring labeled four will slide onto the all thread. Two more nuts will lock this centering ring into place. The CubeSat, will then be slid into the centering ring so that it rests on bulkhead three. The bulkhead labeled five, which will have a square indentation like bulkhead three, will slide onto the all threads and wing nuts will lock this into place. Finally, the whole assembly will slide into the drogue bay and the two all threads will slide into holes in the bulkhead labeled six. Two wing nuts will lock the entire assembly together and the nose cone and drogue bay will be attached together.

IV) Payload Criteria

1. Experiment Concept

Creativity and Originality

Hazard Detection

From a soccer mom parallel parking a van full of kids, to a space shuttle docking aboard the International Space Station, hazard detection systems are used to keep vehicles and people safe. In space travel, safety technologies such as a hazard detection system can mean life or death for astronauts. With that in mind, the improvement of hazard detection systems or devices carries with it an endless level of significance. Project Lambda's Hazard Detection System will help build on this technology and test this kind of system's ability to work aboard high powered rockets.

LVIS

The LVIS payload maximizes the full potential of in line staging by analyzing and comparing the efficiency of two motors during a single rocket launch. While most studies of lateral vibrations have been aimed towards determining how best to dampen the vibrations, this payload takes a different perspective on the problem – to study the connection between the diameter of the motor and the amount of vibrations produced by the motor per Newton of thrust provided. The unique multistage design of the vehicle was created largely because of the requirements of this payload.

Tesseract

The team has chosen to conduct an analysis on the effects of triboelectric charging. This is a phenomenon that occurs when two particles rub against one another, transferring electrons from one particle to the other, creating an overall net charge. In regards to Project Lambda, as it ascends into the air at a high velocity the particles in the air will rub against the nose cone and rest of the airframe of the vehicle stripping away electrons from the air and giving the vehicle an overall negative net charge. This payload uses a unique method to investigate the triboelectric charge that builds up on high-power rockets, integrating topics from different disciplines. Concepts from the study of waves and electromagnetism will be applied to rocketry, unusual in high-power rocketry. In the process, the team will study radio and satellite communications, and construct a CubeSat to be included as a payload in the rocket, another unique feature.

Uniqueness or Significance

Hazard Detection

The edge detection hazard detection system is creative in its own simplicity of design and efficiency. Carrying only the Raspberry pi, camera, transceiver, and a GPS, it is the simplest and most cost effective of the three payloads. Due to much less data being sent to the ground station, the process of detecting hazards and the system making the team aware of them will be a much smoother process.

LVIS

When solid propellant rocket fuel is burned, vibrations travel up and down the length of the rocket. These vibrations create a dangerous environment for electronics onboard the rocket, especially when multiple motors are being used in one rocket, as NASA often has to do to achieve the high altitudes required for its rockets. LVIS will determine whether the rocket-to-motor diameter ratio of the motors used has any effect on how much vibrations are produced. These findings can significantly impact future methods of staging rockets to place the least amount of stress on avionics.

Tesseract

The triboelectric effect, caused by clouds rubbing against the surface of rockets, has in the past been a source of delay for NASA launches. For example, the Ares I-X was supposed to be launched on Oct. 27, 2009, but the launch was suspended due to cloud coverage above the launch site. This payload will collect data that can help understand triboelectric effect in greater depth. The design utilizes three subsystems to try and accomplish this goal, a CubeSat, voltmeter and ground station. The CubeSat is both designed and will be programmed by the team. The voltmeter was suggested as an alternative by the team's electromagnetism professor. It is simple, yet effective. It is designed and programmed by the team and is customized for the purposes of this experiment. A program for the ground station will also be developed in order to receive and read signals sent out from the CubeSat subsystem.

2. Science Value

Science Payload Objectives

Hazard Detection

The objectives of the Hazard Detection System are as follows:

i) Scan the surface of the landing site during descent

ii) Analyze data in real time and determine if landing hazards are present.

iii) Transmit data from the hazard detection system to a ground station in real time.

LVIS

The main objectives of the Lateral Vibrations In Line System are:

i) Record the lateral vibrations produced while rocket is being powered by the main motor

ii) Record the lateral vibrations produced while rocket is being powered by sustainer

iii) Analyze data to determine which rocket-to-motor diameter ratio is safer for avionics

Tesseract

The main objectives of the triboelectric effect analysis payload are:

i) Design a circuit that is capable of accurately measuring the accumulation of triboelectric charge.

ii) Effectively integrate the designed circuit into the vehicle as to maximize the amount of triboelectric charging readings

iii) Measure and record triboelectric charge data with an associated time.

iv) Measure atmospheric conditions, as well as the GPS location throughout the flight

v) Analyze how the accumulation of charge relates to the altitude and time during the rocket's flight

The purpose of this payload is to simply measure data that will help the team understand the triboelectric effect, and how altitude plays a role in the acquisition of this charge. The subsystems will need to work in conjunction with one another to achieve this goal, and will rely heavily on user programming to perform the necessary operations. The first objective will allow the team to acquire reliable data pertaining to triboelectric charging. The second of these will then add soundness to the payload, assuring the team of the most optimal point to obtain valuable data. The third and fourth objectives are what will allow the team to analyze the effects of triboelectric charging post-flight. The last of these objectives permit the team to make a supported conclusions of the payload as a system.

Mission Success Criteria

Hazard Detection

This payload will be deemed successful if it meets the following criteria:

- Detachable bulkhead will fully disengage from avionics bay and e-bay will reorient itself so scanning camera is directed toward landing surface
- Custom designed on-board software analyzes acquired data in real time to determine if landing hazards are present.

- The ground station will be notified in real time if a landing hazard is detected.

LVIS

This payload will be deemed successful if it meets the following criteria:

- The booster section separates from the sustainer and deploys a recovery system
- The sustainer airstarts successfully
- The Raven3 microcontroller measures and records the lateral Gs produced throughout the flight.

Tesseract

The success of the following criteria constitute a successful mission to understand the triboelectric effect:

- Voltmeter is activated by the single axis accelerometer
- Voltmeter gathers and stores measurable data in flight
- Data is recorded and stored onto by CubeSat sensors
- CubeSat sends GPS coordinates wirelessly to the ground station for recovery
- Voltmeter data is successfully interpreted post flight using excel

The mission success criteria was determined based on what was required to answer the research question that has been proposed. The measurement of specific variables, as well as interpretation of these variables, is crucial to successfully furthering the knowledge of the triboelectric charging and its effect on aircraft.

Experimental Logic, Scientific Approach, and Method of Investigation.

The following section describes the experimental thought process in developing rocket payloads. Although the Hazard Detection System has been referred to above as a payload, it has no experimental purpose. Instead, it is designed to perform a specific task. For that reason, its data cannot be classified as experimental.

LVIS

During the research period, the team read about problems that arose during the space shuttle launch of the Ares I-X due to excessive lateral vibrations caused by the motors that could harm the astronauts and avionics aboard the spacecraft. The team therefore devised a payload that was aimed at determining if either parallel or in line staging could mitigate the vibrations produced. However, such a payload required both a parallel and an in line stage, which was deemed to be too risky to execute safely. Therefore, the focus of the payload was slightly altered until it became what it is today.

This payload still studies the lateral vibrations produced by the burning of solid propellant rocket motors; however, now it studies the correlation between motor diameter and the vibrations produced. The rocket's inner diameter is a uniform 6 inches throughout – however, the main motor is 98mm in diameter, while the sustainer is 54mm in diameter. The team hypothesizes that the larger the difference between the motor diameter and the rocket diameter, the greater the vibrational disturbances produced, because the greater space between the motor and the rocket's inner diameter means that, even with centering rings, the motor is not gripped in place as firmly

and thus has more room to move. Therefore, the team expects the 98mm main motor to produce fewer vibrational disturbances than the 54mm sustainer.

Research was conducted to determine how lateral vibrations could be measured and recorded. The Raven3 microcontroller was recommended by the team's mentor as a possible solution. The Raven3 is the perfect fit for the rocket, because of its multiple capabilities and cost efficiency. Not only will the Raven3 separate the booster section from the main and deploy the recovery systems, it will also measure the lateral acceleration experienced by the rocket during each phase of the flight. The team will analyze the data post-flight to confirm or refute the hypothesis that the 98mm main motor will produce fewer vibrational disturbances.

Tesseract

Upon further research pertaining to the measurement of static charge, it was deemed that the triboelectric effect analysis payload needed a more reliable method of recording charge. The previous method yielded inconsistent sets of data. Even without the presence of an electric field, the system would read values, and would also fluctuate. When a charged object would be brought near, the values that the sensor measured would jump very high and then slowly sink down even if the charged object was not moved. Further investigation suggested that measuring a signal-to-noise ratio would not be possible with the current methods outputting in accurate data. The signal-to-noise ratio research question had to be set aside and new methods of measuring charge were investigated.

After discussing alternatives with the team's electromagnetism professor and aiming for a different goal, it was proposed to try and mimic a circuit using the nose cone as a source for charge. Instead of determining how triboelectric charging effects transmitters within the body of a vehicle, the team decided to investigate the relationship between altitude and the charge that accumulated on the surface of the rocket. This will be accomplished by coating the outside of the nose cone with a conductive paint, placing one end of a wire to the nose cone, and the other end to a capacitor and the opposite end of the capacitor will be grounded to serve as a drain for the collected charge. The nose cone will accelerate through the air accumulating charge, which will then tend to drain towards the ground, allowing the charge to move along the wire, to charge the capacitor. The other side of the capacitor will be grounded to ensure that the charge on the nose cone moves towards the capacitor. The analog inputs of an Arduino-based voltmeter will measure the potential difference across the capacitors. The capacitance of the capacitor is known and using the potential difference data, the charge that has accumulated on the surface of the rocket can be determined. The potential difference will have time measurements to go along with them. The CubeSat will be measuring the altitude, and this will also have time measurements to go along with them. The potential difference measurements will be converted to charge. The charge and altitude measurements with corresponding time measurements will be graphed together and the final graph with all altitude and charge measurements will be analyzed to determine the relationship between the two variables.

For this payload, an Arduino-based voltmeter will be used to determine the charge that has built up on the surface of the rocket. A CubeSat has been designed to measure atmospheric data, record the flight, determine the position of this payload, and send out electromagnetic signals

containing data. There will also be a ground station to receive the signals. Together these three systems will help determine the relationship between altitude and triboelectric charge.

Test and Measurement, Variables and Controls.

The following sections explain the testing process for the lateral vibration and Tesseract payloads. Although the Hazard Detection System is also one of Project Lambda's payloads, it is not an experimental payload, but rather is designed specifically to send landing zone data to the ground station. As such, there is no testing associated with this payload.

LVIS

This payload tests the effect of motor staging on lateral vibrations, which is measured in lateral Gs. As such, the independent variable being used is the diameter of the motor in use – 98mm for the main motor and 54mm for the sustainer – while the dependent variable is the amount of lateral Gs produced. The amount of lateral Gs produced is also dependent on the type of motor being used, which is why both the main and the sustainer are Cesaroni motors.

However, the two motors provide different amounts of thrust, which is a confounding variable in the experiment. In addition, because the booster section will jettison from the rocket after the main motor burns out, the two motors will be supporting two different amounts of weight.

To account for this, the team will calculate the net force of the weight and thrust experienced by the rocket during the burning of each motor. Then, the data gathered will be expressed as the amount of lateral Gs of vibrations produced per Newton of net thrust experienced. This ensures that the different amounts of thrust and different weights of the airframe are taken into consideration when computing the data, to verify that the difference in vibrations produced is indeed due to a difference in motor size rather than a difference in forces experienced.

Also, to ensure the most accurate data is collected, every single Raven3 will be measuring the lateral Gs experienced. The primary data collecting Raven3 is the one located in the avionics bay; however, the data will be cross-referenced with the data collected by the Raven3 in the SMART bay. The Raven3 in the mini avionics bay will only record the data for the lateral vibrations produced by the main motor, but this data will also be taken into account and used for cross-reference.

Tesseract

The method used to measure the accumulation of charge is simulating a simple capacitor circuit. The exterior of the nose cone will be coated with MG Chemicals 838 Total Ground Carbon Conductive Coating paint that will allow the nose cone to accumulate charge, acting as source for the capacitor. This source will then be grounded by the other side of the capacitor to draw the static charge. Referring to the fundamental equation for capacitance:

$$C = \frac{Q}{V}$$

where Q is the stored charge and V is the voltage (potential difference) across the capacitor, one can see all that is needed to find the charge stored are the capacitance and the voltage. With these two values the total accumulated charge acquired throughout the flight of the rocket can be determined. For this reason the team has implemented an Arduino-based voltmeter to continuously measure the potential difference across the capacitor and assigning each value with a time stamp. The team will know the capacitance of the capacitor used and have measured values of voltage. Other measurements that are relevant to the experiment include the altitude readings, GPS coordinates and time from the CubeSat subsystem. Altitude will be measured through an altitude/ pressure sensor. This data will also be time stamped and will be compared with data from the voltmeter.

Relevance of Expected Data

Hazard Detection

The expected data for the Hazard Detection Payload is relevant in real time as it will be completely dependent on the landing zone for each flight. The data from test flights will be used to better calibrate the system. As each component in the system has its own acceptable error allowance, the system as a whole will have slight error in the height of each point on the ground. Due to the limited processing power of the system and that data being sent to the ground station in real time, there may be slight delay from when the system detects a hazard and when that information is received on the ground.

LVIS

The expected data is relevant to SLS technology because the way that the rockets are staged can have a major impact on the payloads therein. The extent of this impact can be further determined after analysis of the data collected by the Raven3. The data collected is measured in G force which is the same as weight per unit mass. The Raven3 is accurate to 0.045 Gs and the investigation method requires that the data collected during separation of sections be excluded to ensure that the data collected only includes lateral vibrations from thrust. Another factor that will be taken into account is that the thrust of the motors is differs from the first to the second stage.

Tesseract

The data the team expects to get is applicable to any system that experiences the phenomenon of triboelectric charging or any type of charging by friction. The static charge can build on the exterior of the system, and can then create a potential difference with any type of metal or circuitry within the system, or in the case of Project Lambda the nose cone electronics. This potential difference can present itself as a hazard to communication signals, onboard sensors, or short any other piece of electronics. For this reason the team is investigating the magnitude of charge accumulated during flight at various altitudes, and how this charge is stored on the exterior as a function of time. The data that is being recorded by this payload is charge, time, altitude, humidity and temperature. The data that are critical to the experiment are altitude, time, and charge. Together, this data can help understand how triboelectric charging effects aircraft traveling at different altitudes. The altitude measurements have an accuracy of ± 30 cm. The Arduino can only read voltages between 0 V and 5 V. This electric potential is mapped to values between 0 and 1024. This suggests an accuracy of ± 5 mV. The time increments that the Arduino

can record is accurate to ± 1 millisecond. Although the humidity and temperature data sets are not relevant to the experiment, the accuracy was found to be ± 4 %RH and ± 1 ^{o}C respectively.

Table 14: Accuracy of Measurements

Measurement	Accuracy
Altitude	± 30 cm
Electric Potential	± 5 mV
Time	± 1 millisecond
Humidity	± 4 %RH
Temperature	± 1 ^{o}C

Knowing the accuracy of these components, the error in charge calculations is determined to be as great as 5% depending on the potential differences that are recorded. The altitude measurements are determined to be below 1% for a great portion of the flight. This is within tolerance to make conclusions based on the information we collect.

Experiment Process Procedures

Hazard Detection

The experiment process procedures for the successful outcome of the Hazard Detection System are bulleted below:

Pre-Launch Day

1. Successfully debug edge detection algorithm
2. Perform static and motion tests with objects in the system's line of sight
3. Test communication of data with the ground station specifically looking for time delays

Launch Day

1. Integrate Hazard Detection System into Project Lambda Avionics Bay
2. Receive real-time data sent from XBee at ground station

LVIS

The experiment process procedure for this payload is listed below:

1. Component Functionality Test
    a. Test Raven3 for airstart capabilities

2. Subscale Test Flight
    a. Ensure booster section separates from sustainer
    b. Test ability of Raven3 to airstart sustainer

3. Static Ejection Charge Test
    a. Determine amount of black powder required to separate main bay from booster section

4. Full-Scale Test Flight
    a. Verify that the motor propulsion system that worked for subscale still works for full scale
    b. Test that Raven3 can measure lateral Gs

5. Launch Day
    a. Launch rocket

6. Post Launch
    a. Analyze data to determine which motor produces the most lateral Gs per Newton of net force provided.

Tesseract

1. Research
    a. Look into various methods for recording charge or measuring a potential difference
2. Design process
    a. Design a circuit that is able to accurately measure the triboelectric charge
3. Component Testing (COMPLETE)
    a. Voltmeter
        i. Sensors tested for functionality
        ii. SD card checked to ensure data is stored
    b. CubeSat
        i. Sensors tested for functionality
        ii. SD card checked to ensure data is stored
        iii. GPS tested for functionality and accuracy
        iv. XBee tested to ensure communication between CubeSat and ground station
4. System Testing (COMPLETE)
    a. Voltmeter
        i. System is programmed
        ii. Voltmeter tested to ensure that a potential difference on the nose cone capacitor and extra capacitor can be measured
    b. CubeSat
        i. System is programmed
        ii. All components assembled and tested to ensure the system works as a whole
5. Full-Scale Test Flight (IN PROGRESS)
    a. Systems are prepped using launch day procedures
    b. Nose cone and drogue bay are assembled with specific system components inside
    c. Ground station prepped to communicate with CubeSat
6. Launch Day
    a. Systems are prepped using launch day procedures
    b. Nose cone and drogue bay are assembled with all systems inside
    c. Ground station prepped to communicate with CubeSat
    d. Data is recovered post-flight for analysis

7. Analysis (IN PROGRESS)
    a. Graph CubeSat data
    b. Convert electric potential data into charge data
    c. Compare the two sets of data and make conclusions

3. Payload Design

Design and Construction of the Payload

Structural Elements

a. Hazard Detection

The avionics payload bay is designed to have two main functions. It will house the official scoring and redundant altimeters along with the hazard detection system. The bay will be split internally into two compartments by a ¼ inch Birch plywood bulkhead. The forward compartment, housing the hazard detection system, will extend 7 inches in length and the aft compartment, housing the altimeters, will extend 4 inches in length. The bay itself, is constructed of a 14 inch blue tube 2.0 airframe with a 22 inch coupler of the same material. The coupler will extend 4 inches past the 14 inch airframe on each side and produce a gap of 0.03 inches between its outer diameter and the inner diameter of the airframe. This will provide an easy and secure fit with both the main and the drogue bays. Located inside the coupler, a stiffy tube will act as a stop for the bulkheads. The stiffy tube will be constructed of blue tube 2.0 coupler which will be cut straight down to produce a 5.9 inch diameter, leaving a gap 0.023 inches between the coupler and the stiffy tube. The stiffy tube will then be epoxied 6 inches below the forward compartment and 4-3/4 inches below the aft compartment. G5000 RocketPoxy will be used to secure the stiffy tube, which has a tensile strength of 7,600 psi and compression strength of 14,800 psi.

The bay will contain a total of 3 external bulkheads constructed of 1 inch birch plywood. Two of these bulkheads will remain fixed on each end of the stiffy tube which will enclose and protect the electronics aboard both compartments of the bay. These two bulkheads will be fixed together resting against the stiffy tube via two 14 inch x ¼ inch stainless steel all threads with corresponding nuts and washers on the inside of the bulkheads and wing nuts on the exterior of the bulkheads. The aft bulkhead will contain a centrally located 3/8 inch U-bolt, with a working load limit of 1090 lbs. of force, which will be fastened with nuts and RocketPoxy. This will act as a mounting point for the main parachute. Also, this bulkhead will contain two ¾ inch PVC caps epoxied with RocketPoxy, which will house the black powder for the main parachute ejection. The forward bulkhead of the two will have a ½ inch porthole for the scanning camera and a 3/8 inch forged eye bolt mounted to it. The forged eyebolt has a rated capacity of 1,300 lbs. of force and will be fastened with a washer and corresponding nut, which will also be reinforced with epoxy. The forged eyebolt will act as a mounting point between the Anodized Aluminum L2 Recovery Tether, and the third (detachable) bulkhead. The detachable bulkhead will also contain an identical U-bolt, fastened in the same manner as the U-bolt mounting the drogue parachute. Additionally, this bulkhead will also contain an identical forged eyebolt oppositely directed of the U-bolt, which will act as a mounting point between the tether and the stationary bulkhead. Lastly, the detachable bulkhead will also contain identical PVC caps secured in the same fashion, which will house the black powder for the drogue parachute ejection.

The L2 Recovery Tether will contain two 1/8 inch 316 stainless steel quicklinks on each side, which will be secured to the forged eyebolts on the detachable bulkhead and the fore bulkhead of the avionics bay. The recovery tether is intended for use on rockets weighing up to 60 lbs. with a max deployment load of 500 lbs. and a max shock load of 200lbs. The recovery tether will

contain a compartment in which 0.25g (manufacturer recommended black powder charge) of black powder will be stored. The compartment is then sealed with a pin lock system, which secures the quicklinks on either side. At the event time when main parachute is deployed, the official scoring altimeter will send a charge to the tether system, which will fully disengage the detachable bulkhead from the avionics bay and allow the vehicle to reorient itself so the hazard detection camera can scan the landing surface. The tether system will have a cord attached to it to prevent the pin lock system from separating from the tether system. Additionally, the recovery tether will be covered with a Nomex tether sheath, which will restrain the pins from hitting the airframe and will also add protection from hot ejection charges escaping and damaging/obstructing the camera and/or its line of sight. Lastly, the tether system is ordered from Fruity Chutes, a well-known and trusted supplier of high power rocketry components. Figure 36 displays a visual representation of the tether system used.

Figure 36: L2 Recovery Tether

b. LVIS

The structural design of LVIS involves the three bays of Project Lambda: the mini avionics bay in the booster section, the SMART bay located above the sustainer, and the avionics bay. Each of the bays carries a Raven3 microcontroller that will be recording the amount of lateral vibrations experienced by the rocket. Each Raven3 is mounted on a 4 inch x 5 inch birch plywood payload sled, and a 9V lithium battery is also attached to the payload sled using zip ties. The payload sled is then inserted into the all threads that run through the bay, to keep the Raven3 oriented vertically throughout the duration of the flight. The payload sled is significant for mission success, as the Raven3 needs to be upright during flight to gather accurate data on lateral vibrations.

c. Tesseract

Mount

The mounts for both the voltmeter and CubeSat were designed to fit together inside the nose cone and drogue bay sections. The mount is made up of bulkheads for the nose cone and CubeSat, one all-thread inside the nose cone, two all-threads extending below the bulkhead of the nose cone, and centering rings to restrict the CubeSat from displacing itself during flight. The construction of the bulkheads can be found in the design and construction section of the vehicle criteria. In order to fix the nose cone all-thread, epoxy was poured into the tip nose cone and an all thread was placed inside the epoxy and centered into place with the use of the intended bulkhead for that section. A bulkhead was used to center the all thread while the epoxy cured.

Figure 37: Nose Cone with All Thread Assembled

Once cured, the assembly was constructed using two all-threads extending below the nose cone bulkhead. These all-thread allow the CubeSat subsystem to be centered and fixed into place during flight. The set of all-thread were marked to be cut right below the end of the assembly where the lower bulkhead is epoxied into place. This allowed for the whole assembly of the nose cone and CubeSat to be locked into place by use of wing nuts and thread lock. All the bulkheads will have two ¼ inch holes marked 2.92 inches apart from one another along the diameter of the bulkhead to allow the all-threads to with regular nuts, wing nuts, and washers.

CubeSat Chassis

The CubeSat was designed to be 1.5U with an added compartment for the power sources. The frame needed to be simple, yet strong. For this reason the frame was chosen to be 6061 aluminum, adhering to a compact rectangular frame. The CubeSat chassis started out as a single aluminum square rod. The pieces were measured out, and a metal saw was used to cut them to their desired lengths. The pieces were grouped together by size and filed evenly. Certain pieces were filed down at angles on the ends. This was to create better conditions for the welding. The angles provide more surface for the filler rod to weld to. The pieces were welded together to form two identical rectangular walls. Next, two rods will join the two walls together by drilling two holes at the base and top of each of the walls. The holes were cut out so that a screw would sit flush in them. The two extra rods had holes cut out on each end. These holes were then tapped. Finally, four screws brought the whole assembly together. The walls of the CubeSat were decided to be polycarbonate sheets to reduce the chance of creating a Faraday cage. Each wall was locked into place with 1/16 inch screws and thread lock. One of these walls was designed to have hinges to allow the team to have easy access to the components. Slots were also made along the walls to hold a piece of polycarbonate sheet that mounts the electronics and camera system. Polycarbonate sheets were cut to fit on the outside of the CubeSat chassis. Small holes were drilled into the polycarbonate walls and the chassis. Then, self-tapping screws were used to connect three of the walls. A hinge was used to connect one wall to the chassis for ease of access to the electronics within the CubeSat.

Voltmeter

The Arduino based voltmeter was designed to be used to measure the potential difference across the nose cone capacitor, as well as the extra capacitor that the team has implemented. The analog inputs of the Arduino will be used to measure the potential on each side of the capacitors. The capacitors were put in parallel to increase the capacitance and allow more charge to be stored. The single axis accelerometer became a part of the circuit due to the need for a self-starting data acquisition sequence. Hence, once motor ignition has begun the single-axis accelerometer will record these changes and initialize the data logging sequence.

CubeSat

The CubeSat electronics required no construction; however, some of the components needed to be assembled. All the shields required the soldering of stackable headers. The wires that were required for communication between components were also soldered to ensure no loose connections. All the components that require to be connected to the Arduino board will be soldered onto the SD card shield to assure the team the connections do not jostle loose during flight. The XBee, altitude/ pressure sensor, and humidity/ temperature sensor will be mounted to grid style boards. The grid style board and Arduino are each mounted to a piece of polycarbonate

that fits in the slots of the CubeSat chassis. The camera will be mounted onto the polycarbonate sheet with the components. The components were chosen to perform specific tasks to help with the mission. However, the camera and humidity/ temperature sensor were not intended to help further the research.

Electrical Elements

a. Hazard Detection

A Raspberry Pi computer as the controller and processing unit for the Hazard Detection payload. This computer will connect to a RockSoul USB webcam through USB with wires soldered directly to the four lead on the ports to prevent detachment during flight. There is also an Adafruit Ultimate GPS Breakout Board connected to the Pi through a TTL Serial connection.

b. LVIS

LVIS utilizes two Raven3 altimeters outside of the main avionics bay to gather the most amounts of lateral vibrations. These locations are the mini avionics bay, located in the booster section, and the SMART bay located above the sustainer motor. Each of these bays is 4 inches in length with a diameter slightly smaller than 6 inches, and each bay contains a removable payload sled made from birch plywood. The payload sled is the retention board for avionics, and its dimensions are as follows: the sled is 4 x 5 x ½ inches and contains two ½ inch pieces of plywood that is wood glued to two slots within the board. Additionally, there are two 1/4inch holes in each of the plywood pieces that are wood glued to the sled and have been sanded to allow for ¼ inch all thread rods to fit inside. Each bay contains two, ¼ inch all thread rods attached on one side by epoxy to a 1 inch bulkhead and sealed from any black powder charges using a removable bulkhead with washers, nuts, and nut lock to keep the bay sealed. Using the same materials and configurations in both bays allows the information which is collected by the Raven3 to remain unaffected by the sleds. The Raven3 located in the main avionics bay relies on a similar sled configuration. For details on the retention of the main avionics bay, please see page 61.

Each of the sleds contains a front side which all of the electronics are mounted to using screws, washers, and nuts, and a back side where batteries can be attached. In the mini avionics bay and the SMART bay, the batteries are attached by drilling eight holes, two on each side of the battery and using four zip ties through the holes, the team can secure all batteries. This mitigates the risk of the electronics failing to turn on from lack of connectivity to a battery and assists in a safe flight.

An additional safety consideration is the arming of igniters and pyro charges, for this reason, each Raven3 utilizes a switch which attaches to the rocket body and can be armed outside of the rocket. This switch mitigates the risk of an igniter or pyro charge igniting prematurely. The RockeTiltometer2 also has uses three switches accessible from the outside of the rocket body. The first of which is to turn on the system and set the zero angle. The second is an igniter battery switch and lastly is the igniter arming switch. The switches uses for the RockeTiltometer2 ensure that the proper zero angle is selected and a safe ignition of the igniter occurs.

The Raven3 in the booster section has two igniters – one in the “main” pin, and the other in “3rd”. The igniter in the “main” pin is able to deploy the booster section parachute using the

flight logic of pressure increasing and altitude above 512ft AGL. The igniter in "3rd" is in charge of the stage separation which is set to ignite 2seconds after liftoff. The Raven3 detects liftoff when the axial accelerometer detects 3G's which according to the user's manual translates to "3mph upward velocity". Even though the Raven3 is able to detect liftoff, the battery will not be switched on until the rocket is ready on the launch pad. The Raven3 in the SMART bay is connected to the RockeTiltometer2 using a 22 gage insulated copper wire from "3rd" output of the Raven3 to the ground pin2 of the RockeTiltometer2 in terminal 2. The flight logic used for the Raven3 is a pure timer of 2.5 seconds after liftoff detection occurs. The wiring for the Raven3 with the RockeTiltometer2 can be seen in the electrical diagram below.

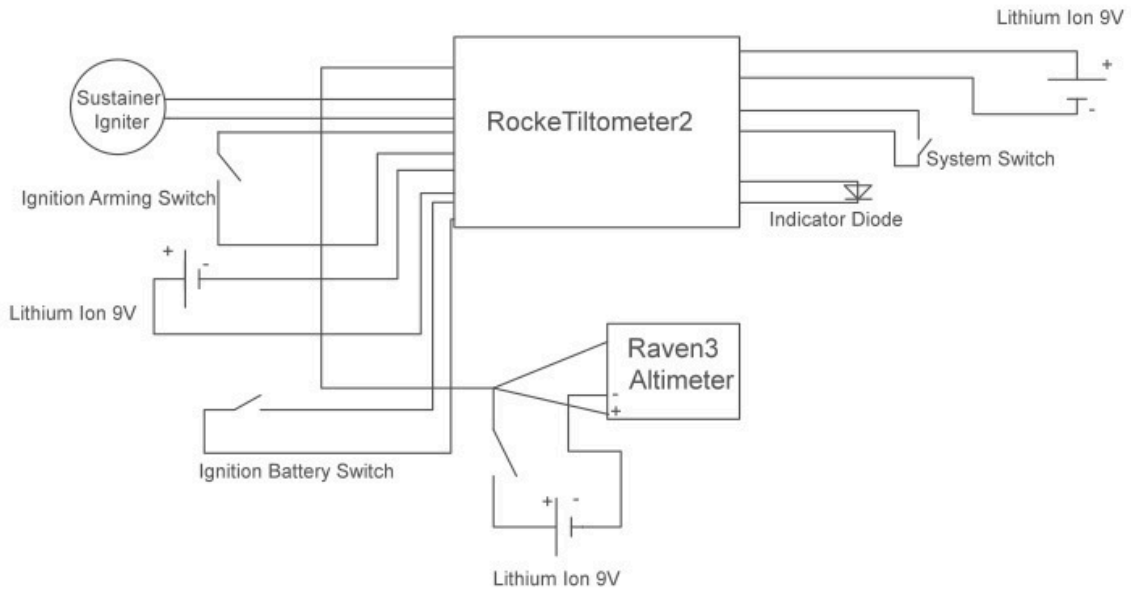


Figure 38: Electrical Diagram of Raven3 and RockeTiltometer Configurations

c. Tesseract

The Tesseract payload has two subsystems that require electrical assembly. The schematics for these electrical systems can be found in the next section.

Figure 39: Conductive Nose Cone

The Voltmeter system will start with the conductive paint on the nose cone that will act as a source for charge. One end of the wire will be connected to this painted surface, then connecting to a capacitor at the other end. The opposite side of the capacitor will be connected to one of the ground pins on the Arduino Uno microcontroller. The analog input pins 0 and 1 will be soldered to opposite sides of the capacitor to read the potential difference that is created between the two ends of the capacitor. The single axis accelerometer will be soldered onto the SD card shield and be connected to the 3.3 V pin, the ground pin, and analog input pin 3 of the Arduino. The battery source for the Arduino will be connected to an enclosure on the electronics sled. The enclosure consists of four birch plywood walls, two for the sides, one for the top and one for the base, with a polycarbonate sheet that is held on by hinges. The four pieces of plywood were sanded and epoxied onto the electronic sled first. Then the hinges were placed onto the polycarbonate sheet and one of the side walls. The opposite side then secures the door closed with a screw for launch day. The top of the enclosure is cut out to allow the cable to run to the Arduino. The Arduino will be mounted onto a polycarbonate sheet separated by spacers and then screwed onto the electronic bed. The Arduino has four holes for screws to be placed and the Arduino will be held tight enough to withstand the forces that it will experience during flight.

The CubeSat is a more complicated system and requires more wiring to operate. The SD shield and GPS shield will both be mounted onto the Arduino Uno microcontroller. The GPS Receiver EM-406 will be mounted on top of the GPS shield and a 32 GB microSD card will be used to store all data logging. The humidity/ temperature sensor is connected to analog pins 0 and 1, and the altitude/ pressure sensor is connected to analog pins 4 and 5. Additionally, each will be connected to the 3.3 V and ground pins of the Arduino. The XBee will be connected to the 3.3 V and ground pins, but it will also be connected to the digital pins 5 and 6. The camera will have its own dedicated 3.7 V power source that will be connected to pins 1 and 2. The digital pin of the Arduino will be connected to the switch/ button pin will be connected to the Arduino so that the Arduino can act as the switch. Finally, an LED will be connected to pins 7 and 9 on the camera to indicate whether or not the camera is recording. The Arduino and the shields will be connected to the uppermost shelf of the CubeSat chassis. In a similar way that the voltmeter Arduino was mounted to the bulkhead. The Xbee and sensors will be connected to the lower shelf of the CubeSat chassis and the camera will be connected to a polycarbonate sheet that stands between the upper and lower shelf. The components will be connected to a grid style board that is screwed onto the shelf. The camera also has places for screws and these will connect it to the polycarbonate sheet. There will be two batteries that will be within the CubeSat. The bigger of the two will stand up and fit through a cutout on the lower shelf. The battery will then be strapped down with zip ties. The smaller battery will simply lie in the lower compartment of the CubeSat chassis and will also be strapped down with zip ties.

Drawings and Schematics

a. Hazard Detection

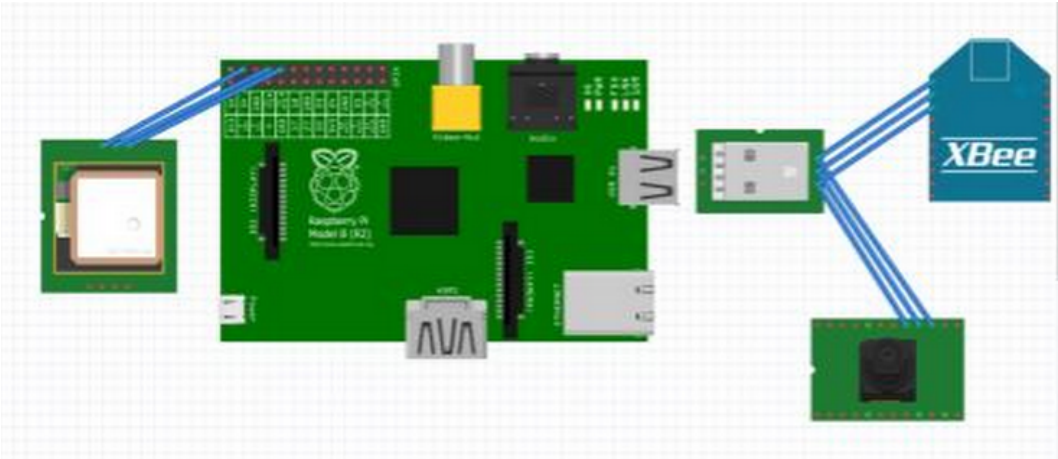


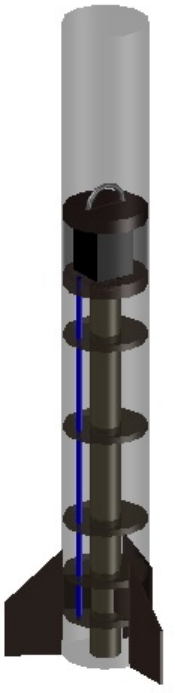
Figure 40: Hazard Detection Schematics

The Hazard Detection payload includes four electronic components; a Raspberry Pi, RockSoul USB webcam, Adafruit Ultimate GPS Breakout Board, and a XBee Pro 900. Powering all of these components is a Kmashi 11200 mAh USB battery. The Raspberry Pi is connected to the battery with a USB cable on the battery side and the other end of the wire soldered onto the lead for the mini B power port. The Adafruit GPS is connected using UART to the Raspberry Pi. This requires a cross connection between the TX and RX pins on both board. Power from the battery is supplied to the GPS through the VIN pin from the 5V pin. The RockSoul camera is a common

USB webcam connected to the Pi's USB port. The port itself is not used, instead the wire between the two components is soldered into the 4 leads used by the USB port. The XBee Pro is connected by wire soldered to the 4 leads of the second USB port on the Pi.

b. LVIS

Figure 41: LVIS 3D Diagram



The primary difficulty in constructing a two-stage rocket is ensuring the proper orientation of the igniter and smart devices that are intended to air start the sustainer motor. Figure 41 shows a 3-dimensional drawing of the sustainer tube and main parachute bay. Directly above the motor mount, their lies a 1 inch thrust plat that will simultaneously act as a bottom bulkhead for the SMART bay, represented in Figure 41 by a black box. In order for the igniter to be controlled by the smart ignition electronics, a steel electric conduit, represented in blue in the diagram, was placed through the thrust plate, and down past the bottom centering ring surrounding the sustainer motor mount. Electric wire slides through easily, and the igniter for the motor can be connected from the bottom.

The top bulkhead of the SMART ignition electronic bay serves as a tether point for the main parachute. These bulkheads are extremely resilient, and can withstand all forces induced by parachute deployment.

Two separate ¼ inch all thread rods will connect the two bulkheads. A stiffy tube is placed in between them to secure the bay into place.

c. Tesseract

The payload that is to be launched in the rocket consists of the CubeSat and voltmeter. The following diagrams will show how they are connected.

Figure 42: Simplified Version of Voltmeter

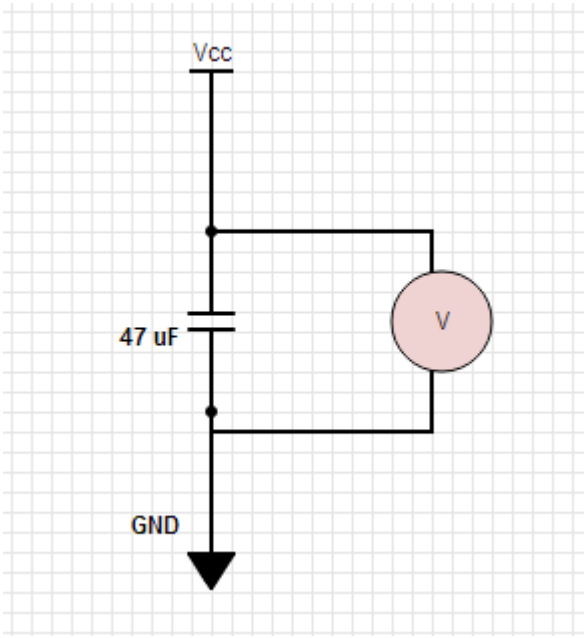


Figure 43: Wiring Assembly of Voltmeter Subsystem

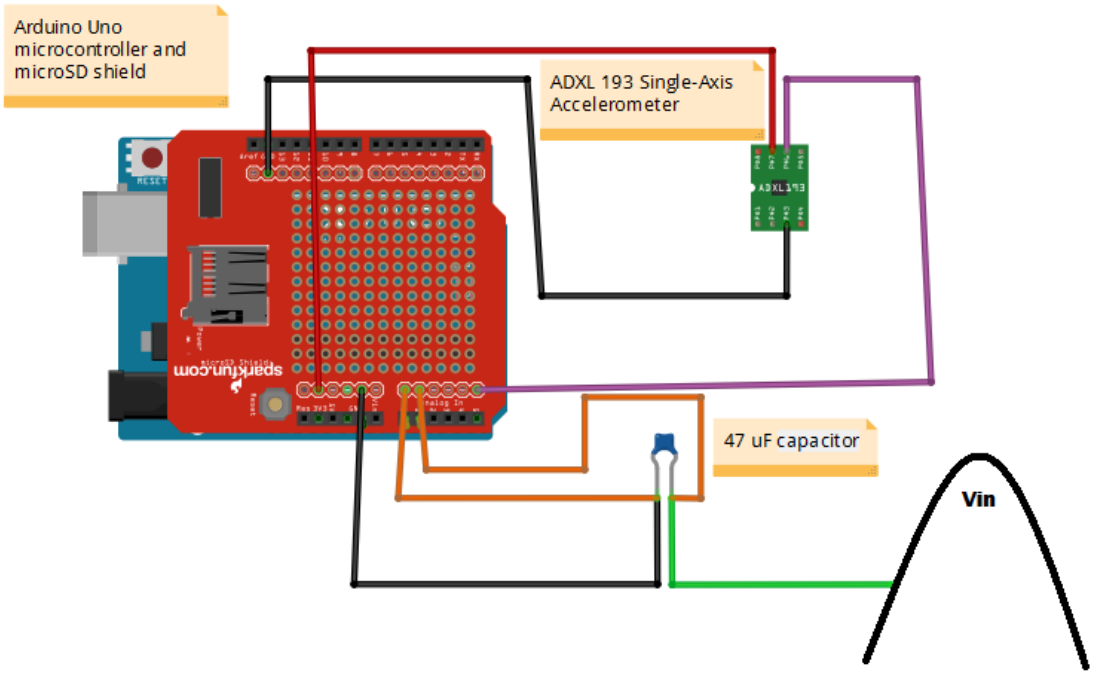


Figure 44: Wiring Assembly of CubeSat Subsystem

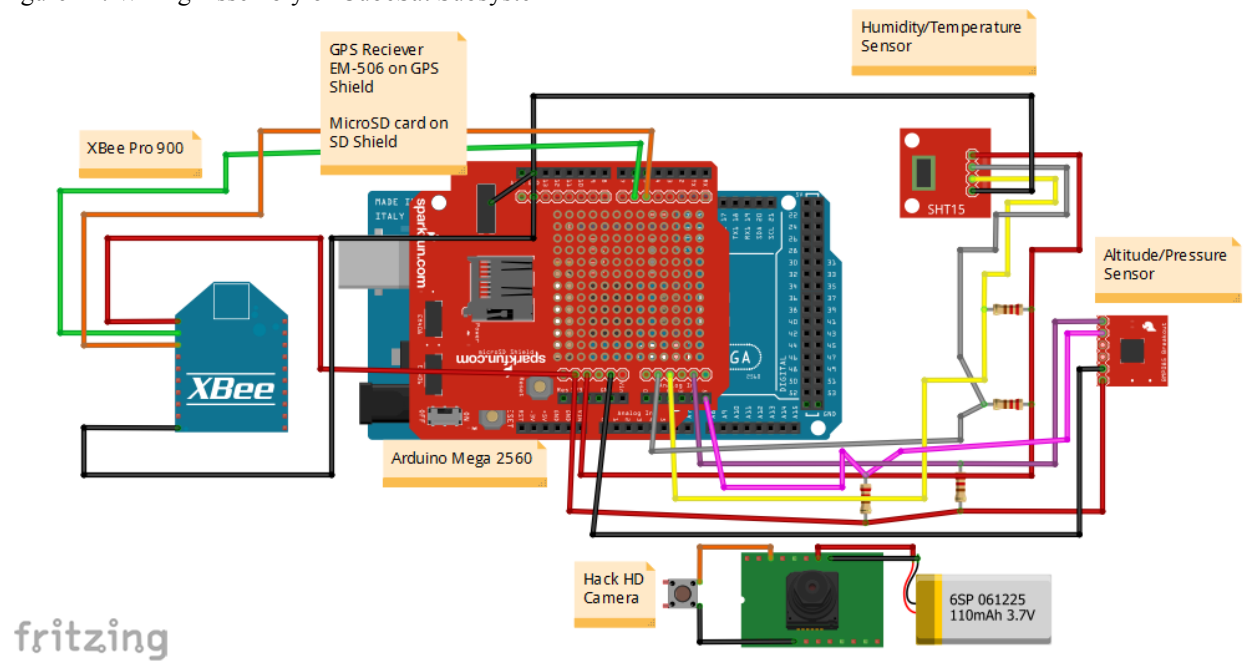
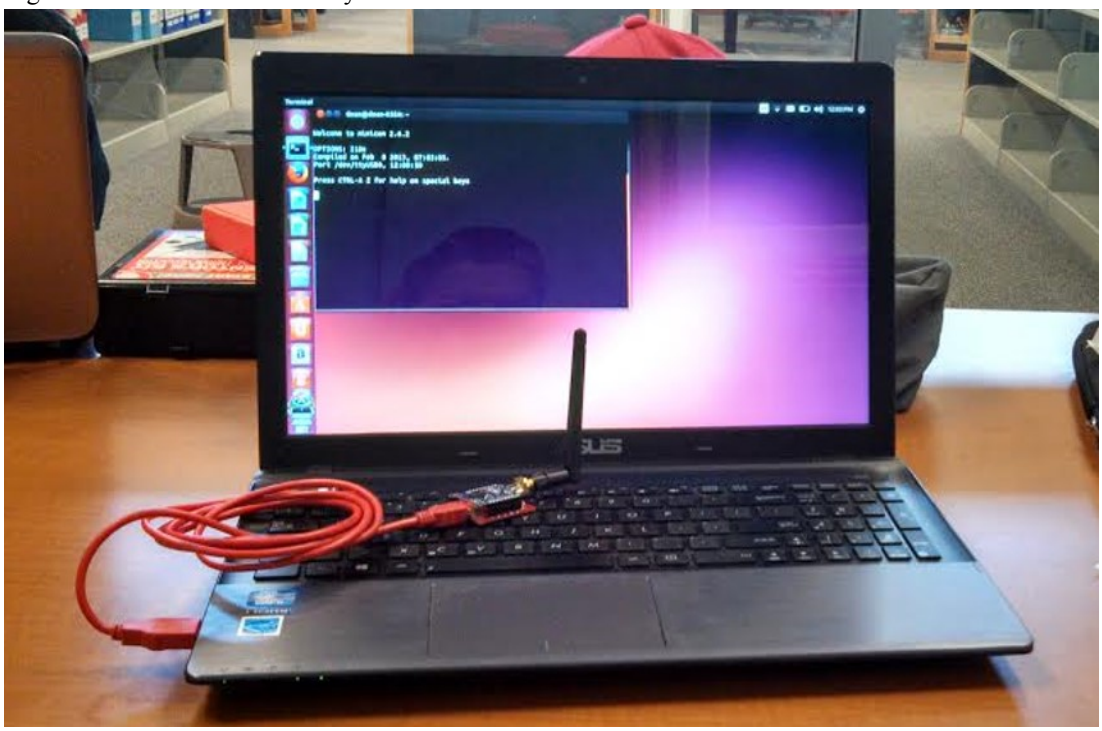
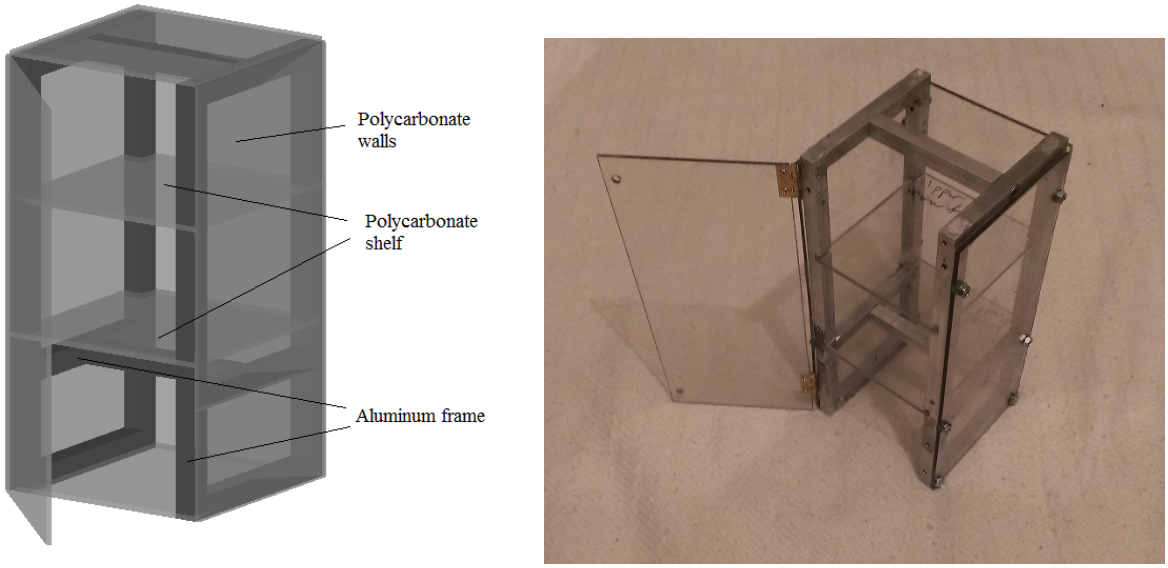


Figure 45: Ground Station Subsystem



The chassis is a 10 x 10 x 20 cm square made of aluminum. Polycarbonate sheets will be used to mount the components into the chassis. The following diagram shows the assembly of the chassis.

Figure 46: 3D Drawing and Actual CubeSat Chassis



Precision of Instrumentation and Repeatability of Measurement

LVIS

The Raven3 contains an accelerometer which is user calibrated and can be up to 5% error due to this calibration. After speaking to the manufacturer, it has the potential of more error in axial acceleration if the flight is low velocity or off axis. This percent error will not affect the data collected as the team is only concerned with the lateral vibrations produced by the rocket motors while burning. However, the manufacturer did state that the lateral acceleration can have up to 5% error from calibration which will be taken into account when analyzing the data. In order to mitigate the user calibrated error, the team has calibrated all Raven3 altimeters on a level surface using a protractor to ensure the microcontroller is exactly 90 degrees. The Raven3 uses a factory calibrated barometric sensor which is extremely accurate when sensing pressure and has a percent error of 0.1%. This however increases when converting pressure to temperature as the calculation is based off of the International Standard Atmosphere model. This conversion will not directly affect the data collected as the team does not use the temperature in neither the flight logic nor, data analysis.

The Raven3 can hold up to five flights of data which allows the team to repeat the launch and compare results. Additionally, the Raven3 allows the user to customize and save specific flight logic which then can be uploaded to other Raven3 altimeters or used for future launches. The Raven3 specifications directly from the manufacturer's web site are listed in the table below.

Tesseract

The triboelectric effect payload can be split into two systems. Each of these systems have their own instruments used for measuring different sets of data. The CubeSat measures altitude, humidity, temperature, and time. The voltmeter measures a potential difference across capacitors, time, and also makes use of a single axis accelerometer. The accuracy of the altitude is ± 30 cm. The accuracy of the temperature sensor is ± 1 ^{o}C. The humidity can be determined to

± 5 %RH. The voltmeter can measure with an accuracy ± 5 mV. Both systems can measure time with an accuracy of ± 1 millisecond. The precision of the single axis accelerometer is not relevant because the data from this sensor is not being recorded. This sensor is being used to activate the acquisition of data from the voltmeter when an acceleration is detected. The only component that needs calibration is the humidity sensor. This component must be re-hydrated if the conductive polymer within the sensor gets to dry. This sensor must be place in an area that is room temperature under ambient conditions.

The two systems can record as many flights as needed to allow the team maximum data. The only limit is the capacity of the SD cards. The voltmeter has been tested on capacitors and has yielded precise results trial after trial. The sensors from the CubeSat have also shown precision in data acquisition. Assuming the programming doesn't change, and similar conditions between trials, multiple experiments should yield similar results.

Flight Performance Predictions

Hazard Detection

Table 15: Hazard Detection Flight Performance Predictions

Flight Event	Payload Operation	Altitude (ft.)	Velocity of Rocket (ft/s)
Main Parachute Ejection/Detachable Bulkhead Separation	The vehicle will reorient itself so that the forward compartment of the avionics bay is directed toward the landing surface. Following reorientation, the scanning camera will capture images of the landing surface, where the data captured will be analyzed for potential landing hazards and sent to a ground station in real time.	1200	54

LVIS

Table 16: LVIS Flight Performance Predictions

Propulsion Event	Payload Operation	Time into Flight (s)	Velocity of Rocket (ft/s)	Mass of Rocket (lbs)
Main motor ignites	The three Raven3 microcontrollers measure lateral vibrations produced by main motor	0	0	52.4
Sustainer motor ignites	The two Raven3 microcontrollers, one in the SMART bay and one in the avionics bay, measure lateral vibrations produced by the sustainer	2.5	270	35.9

Tesseract

Table 17. Tesseract Flight Performance Predictions

Propulsion Event	Payload Operation	Time into Flight (s)	Velocity of Rocket (ft/s)	Mass of Rocket (lbs)
Main motor ignites	CubeSat and Voltmeter data acquisition sequence activated, camera starts recording and XBee sends GPS coordinates to ground station	0	0	52.4
Sustainer motor ignites	CubeSat continues to collect data and send GPS coordinates, voltmeter continues to collect triboelectric charge in the capacitor and camera continues recording	2.5	270	35.9
Landing	Data from systems stop recording, capacitor stored the maximum amount of charge and the voltmeter recorded measurable potential differences, and GPS are continued to be sent to the ground station		0	

Workmanship

The payloads that have been designed for this rocket have evolved as this project has moved on. Extensive research has been done in order to come up with payloads that suits the requirements of this project. As the project has progressed, testing has been performed on these payloads to ensure that they functioned properly. However, some of the payloads have required changes. The team has been working hard to make the payloads work the way they were intended, but has also realized that some of the objectives weren't feasible in the span of this project. The loss of the parallel boosters and the drop of the signal-to-noise ratio calculations serve as examples of drastic changes made in order to complete the project.

Throughout this project, the systems that have been designed have gone through extensive testing to ensure that they are not only functional, but also accurate. A lot of research has also gone into programming the components and many hours of troubleshooting have gone into making the systems of the Tesseract payload operate properly. Testing has even gone into the test flights. The Raven3 microcontrollers have been tested within the body of the rocket to ensure that they are fully capable of performing the necessary task that they were chosen for.

The team understands that effort in creating a payload that can help further research in aerospace related topics is just as important as creating a vehicle that can carry these payloads. The team has put forth all its efforts into ensuring that the payloads work. This includes, many hours of research, building, and testing. These efforts have led to payloads that are nearly complete and will add to the scientific understanding of the world of today.

Test and Verification Program

The test and verification of the payloads follow a simple plan use to verify if a component meets a requirement or is needed by a system to meet a requirement.

a. Component to be tested
b. Features to be tested
c. Approach
d. Test
e. Risks involved with using component
f. Approval

4. Verification

System Level Functional Requirements

Hazard Detection

In order for Hazard Detection System to be considered a success, the design must satisfy the system-level functional requirements detailed in Table 18 below.

Table 18: Hazard Detection Functional Requirements

#	Payload Requirement	Design Feature	Verification	Status
3.1.1	The payload shall incorporate a camera system that scans the surface during descent in order to detect landing hazards	The vehicle will have a Raspberry pi camera board in conjunction with a Raspberry pi model B/The recovery system will reorient the position of the payload bay so the face of the camera is directed toward the intended landing surface	Test launches on the full scale vehicle will confirm the successfulness of reorienting the vehicle	In progress
3.1.2	The data from the hazard detection camera shall be analyzed in real time by a custom designed on-board software package that shall determine if landing hazards are present	Edge detection algorithms will be programmed into the Raspberry pi/OpenCV will be utilized as a source of reference	Elevated/ground static and motion tests will be performed with stationary objects in its line of sight to demonstrate accuracy and precision of edge detection	Complete
3.1.3	The data from the surface hazard detection camera and software system shall be transmitted in real time to a ground station	A pair of XBee Pro 900 RPSMA will be used to transmit data from the vehicle to a ground station in real time	Elevated static and motion tests will be performed with communication system focusing on any time delays	Completed

LVIS

Table 19: LVIS Functional Requirements

Subsystem	Functional Requirements	Verification	Status
In-Line Motor Stage	Reach 1350 ft. AGL before main motor burns out and detaches from rocket so sustainer can ignite	Full scale test launch	In progress
Featherweight Raven3	Record lateral G-force produced by motor stages during the flight.	Subscale test/Full scale test	Completed. Successfully recorded lateral Gs for subscale. Full scale testing in progress

Tesseract

In light of the Tesseract payload changing since the CDR, the team has had to modify the payload success criteria. In order for this system to be considered a success, the outer conductive paint must allow for the nose to collect enough triboelectric charge to be stored by the capacitor and the voltmeter can record a measurable potential difference. The functional requirements for the system to perform as expected are that the CubeSat and voltmeter must initialize their data logging simultaneously upon ignition. Additionally, the CubeSat must establish a communication line with the ground station at the beginning of the launch to transmit the GPS coordinates. Most importantly, the two onboard subsystems must store and save their data during their defined time intervals to allow the team to analyze the collected data post launch. The following table expands on the requirements for each subsystem to contribute to the success of the Tesseract payload.

Table 20: Tesseract Functional Requirements

Requirement	Compliance	Status
Detect, record and collect data pertaining to the accumulation of triboelectric charging on the nose cone of the rocket	The voltmeter will be located in the nose cone and is designed to drain the build-up of static charge into a capacitor and record the potential difference across the capacitor onto an SD card	Ground test have been made to confirm the voltmeter can measure an accurate potential difference. Scale flight tests are planned before competition to allow time for any last minute adjustments to the measuring
Atmospheric measurements, with emphasis on altitude, must be made and recorded during defined intervals throughout the flight	The CubeSat's microcontroller incorporates a loop structure that defines intervals of ten measurements per data set. Each set of data will be saved onto an SD card for post flight analysis.	Sensors used for atmospheric data have been tested individually and as a single system

Requirement	Compliance	Status
At the end of the launch, the XBee must begin to send GPS coordinates to the ground station	The Arduino is programmed to begin communication upon launch with the use of the altitude/pressure sensor and 900 MHz XBee Pro wireless modules	Testing for the XBee Pro 900 have been made at various distances sending out GPS data sets. This allows
Payload must be reusable	Housing for each subsystem is designed to safeguard the onboard electronics during the flight and upon landing to allow for use in multiple launches	Ground tests have been done with the separate housing of each subsystem to analyze their durability and strength
Payload must be recoverable	The Tesseract payload will make use of a USGlobalSat EM-406A GPS that will store the data onto the SD card and assist in the recovery process	Ground tests have been done that ensure the GPS is within the team's accuracy and expectancy

Analysis, Inspection, and/or Test

Hazard Detection

The Hazard Detection was tested in two steps. Step one, the algorithm was tested. In this test a random 800x600 pixel image was uploaded to the raspberry pi. This image was then ran through the algorithm generating a similar image were surfaces were displayed as black and edges were clearly defined white lines. The raspberry pi and algorithm passed the test of processing an image. The second test was to get the raspberry pi to access the RockSoul webcam to take a picture and process it through the algorithm. This test did not pass on the first few tries. Interfacing between the camera and Pi required multiple changes to the OpenCV code used by the raspberry pi. The requirement is met but further tweaking is needed to improve efficiency.

LVIS

The testing for the LVIS payload included ground testing operations prior to flight. The first ground test included the use of a 9 volt battery to ensure adequate current is sent outputs to ignite black powder charges or the sustainer. The system of utilizing three Raven3 microcontrollers was tested in the full scale flight. The test flight resulted in two of the three Ravens working flawlessly. The booster section separated and deployed its parachute exactly as designed. The Raven3 used as the scoring altimeter did ignite the ejection charges for the main parachute, however the parachute didn't deploy due to an error in packing. Unfortunately, the 9 volt battery used in the SMART bay did not supply enough current for the igniter to light. This was not a problem with the last Raven3 itself but a combination of the e-match and low current battery. It did not light the sustainer motor at all, resulting in a much lower apogee than planned with the sustainer firing. Another test launch should allow for any corrections to allow full a completely successful set of

Raven3 altimeters. Testing of the LVIS payload also includes testing the barometric sensor of the Raven3 by use of a sealed tube, a buzzer, and a bicycle pump.

Tesseract

The Tesseract payload utilizes many components to meet its requirements. Table 21 shows the component and the test used for verification.

Table 21: Tesseract Verification Test

Component/Test	Rationale	Test
Humidity/ Temperature Sensor Component Test	To ensure that this component functions within the accuracy of the manufacturers.	A section of code was written to run this component on the Arduino Mega. The component will be static tested on the ground and have its measured values compared to local weather station values to measure the accuracy.
Altitude/Pressure Sensor Component Test	To ensure this component records data within the manufacturer's accuracy.	A section of code has been written to record atmospheric pressure and output the current altitude. This data will be cross-referenced with known local altitude values.
Single Axis Accelerometer Component Test	To ensure that this component functions records data and is within the manufacturers accuracy.	A section of code still needs to be written to run this component on the Arduino Uno. When this has been completed, it will be ground tested to measure the acceleration due to gravity with a series of "drop tests". The collected data will be analyzed and cross referenced with the manufacturer accuracy.

Component/Test	Rationale	Test
XBee Pro Wireless Transceiver Functional and Static Test	To ensure that two of these components will communicate with one another during flight and do not interfere with the XBee transceivers from the Hazard Detection System. Additionally, we want to ensure they can communicate at the distances we require.	The XBee transceivers being used in the CubeSat and at the ground station will be ground tested first by writing a portion of code to have the Arduino collect data from one of the sensors, store it onto the SD card, and send the data via Serial communications link to the ground station. Additionally, we will conduct a similar test but with the Hazard Detection system with close proximity and functioning to see if any interference occurs. Testing will be done up to a range of 4 miles to imposter the distance of the team's vehicle. Advanced serial data loggers are currently being looked into.
Humidity/ Temperature Sensor functional Test	To ensure that this component records accurate data during flight data.	A section of code has already been written to operate this component and display the data. This component will also be used during flight in of the team member's personal rockets. The collected temperature and humidity data will be compared with readings from local weather stations.
Altitude/ Pressure Sensor Functional Test	To ensure that this component records reliable during flight data.	A section of code has already been written to operate this component and save the collected data. Additionally, this component will be tested during flight in one of the team member's personal rockets along with the Raven3 to compare the altitude measurements of both products. This will allow the team to simulate changing atmospheric conditions during flight. Since altitude is determined through formulas using pressure, only one needs to be tested to determine the accuracy of both.

Component/Test	Rationale	Test
SD Card Functional Test	To ensure that data can be saved from any sensor that needs data recorded.	For every section of code that was written to operate a sensor, part of the coded loop was made to save the data it collects to the onboard SD card. Functional testing is performed with the SD card and shield connected to the Arduino so that testing performed for each sensor is being saved on the SD card. It is later checked to see if the data was being properly saved.
CubeSat Subsystem Testing	To ensure that the CubeSat's components can successfully operate together as a single unit.	As functional testing continues, the different components that have already been tested, will be tested in the CubeSat on the ground. This is to ensure that the code written for multiple components functions accordingly. Further testing will also be done during the control test.
Ground Station Functional Test	To ensure the custom program collects the incoming serial data and compiles the data.	The custom program will be ground tested with the XBee Pro transceivers primarily to establish the communication. Then, during the control experiment and functional testing of sensors the ground station will run the custom program to ensure its functionality.
Voltmeter Static Test	To ensure that this subsystem can detect any electrical potential difference.	The transistor still needs to be purchased so the circuit can be assembled. Once assembly is completed, objects with a potential difference across two sections, will be will be measured by the voltmeter and the data will be monitored for any charge that it detects.
Voltmeter Functional Test	To ensure that this subsystem can accurately detect a potential difference.	Different objects with a known potential difference on two spots will be measured by the voltmeter and the data will be carefully analyzed to ensure that the data that is collected is accurate.
Full-Scale Test Launch	To ensure the functionality of certain systems within the body of a rocket.	The Arduino for the CubeSat, as well as the GPS and XBee will be launched in the full-scale test flight to ensure that the recovery subsystem of the payload works properly.

5. Safety and Environment (Payload)

Safety Officer

Joshua will act as the safety officer for the Citrus Rocket Owls. The safety officer's main responsibilities are outlined in the vehicle safety section. With the payloads, the safety officer is to oversee the team in the construction of the payload components and also ensure that the electronics are not interfering with each other or running the risk of setting off any black powder charges prematurely.

Payload Analysis of Failure Modes

Table 22: Hazard Detection Failure Modes

Risk	Causes	Consequence	Mitigation	Risk Level
Residue from black powder charges cover camera porthole.	Black powder charges can easily leave residue on the surfaces in the tube where it was deployed.	Unable to detect hazards, invalid edges detected.	A cover is placed over the porthole to prevent damage or residue from the black powder.	2
Other sections of the rocket obscure the hazard detection system during descent.	Poor recovery design, improper lengths of shock cord used in the rocket.	Camera images of landing zone obscured.	The altimeter bay will have a longer shock cord than that of the main parachute bay to allow the altimeter bay to hang lower during descent with a clear view of the ground.	4
The detachable bulkhead not separating correctly.	Black powder in tether didn't ignite, tether gets stuck on quicklinks.	The camera will not take any valid pictures for hazard detection.	Ground testing of detachment using black powder to cut nylon line.	6
Battery failure or overload.	Didn't charge battery, manufacturing defect, battery left in extreme temperatures.	No power to system, damage to electronics.	Ground testing of rechargeable batteries and use of new 9 volt batteries.	2

Table 23: In Line Motor Failure Modes

Risk	Causes	Consequence	Mitigation	Risk Level
Motor ignition failure	Improper handling or setup of motor, high humidity, failure of igniter or launch system.	Data collected will not determine the benefit of staging as a motor failed to ignite.	High heat 3M foil tape will be used to secure igniters in motors to keep them in place throughout the launch.	8
Raven3 does not separate stages	Poor programming of the Raven3, failure of battery.	Data collected is not accurate.	Raven3 has been ground tested and launched in subscale prior to full scale launch.	8

Table 24: Tesseract Failure Modes

Risk	Causes	Consequence	Mitigation	Risk Level
Triboelectric charge on surface of the rocket is not strong enough for voltmeter to sense	Rocket did not accelerate fast enough or did not travel far enough through the atmosphere.	Voltmeter will not take any useful data	Coat the nose cone with a layer of carbon fiber to help acquire charge. The voltmeter will also be calibrated to optimize efficiency.	12 (8)
Voltmeter doesn't know when to start taking data	Arduino doesn't know when the rocket has launched.	Once activated, the voltmeter will take data instantly creating useless data and making calculations much more error prone.	The voltmeter will be equipped with an accelerometer that will tell the Arduino when the vehicle launches. The Arduino will then tell the voltmeter to start taking data.	5
The electromagnetic waves sent out by the CubeSat cannot be detected	Unexpected interference, component failure.	Experiment will be incomplete. All other data cannot be analyzed and conclusions cannot be made.	Ground testing will be conducted to make sure that the ground station can receive signals while the CubeSat is far and moving.	12 (6)
Circuitry wiring comes loose during flight	Poor soldering, strong forces during thrust.	The CubeSat will not take the data that it is required to take and the experiment fails due to lack of data.	Wires and circuitry components will need to be soldered together. Everything will need to be mounted properly so that movement during flight is prevented or minimized.	9 (6)

Risk	Causes	Consequence	Mitigation	Risk Level
Barometer activates data acquisition sequence too early or too late	Poor programming, poor wiring	Timings will be off and data is no longer reliable.	Ground testing will be required to test the barometer for accuracy. Careful soldering by the most experienced members of the team.	8

Failure Modes and Effects Analysis

Table 25: Failure Modes and Effects Analysis

Risk	Likelihood (1-5)	Severity (1-5)	Consequences	Mitigations
Triboelectric charge on surface of the rocket is not strong enough for voltmeter to sense	3 - Difficulties reading the charge on the nose cone accurately.	4 - If the charge cannot be detected the payload will fail as a whole.	Failure of Tesseract payload, reduction of scientific value for the project.	The nose cone is coated in several coats of carbon paint.
Raven3 does not separate stages	2 - The Raven3 has a built in redundancy so it is unlikely to happen.	4 – If the stages don't separate, the sustainer will still light and force off the booster section.	Significant damage to the booster section due to the motor's thrust. Data on lateral vibrations might be flawed.	The Raven3's own redundancy. The black powder charges are measured to have enough force to break the shear pins and separate the booster from the sustainer.
The detachable bulkhead not separating correctly.	2 – The recovery tether used to detach the bulkhead we shipped late and as such the device has had been tested very little.	3 – If the bulkhead does not detach, the hazard detection camera won't be able to see the ground.	If the bulkhead doesn't detach it will block the view of the camera. This will cause the payload to have no valid data.	The recovery tether used to detach the bulkhead it trusted by the team's mentor to detach consistently. Further testing will be done during more full scale flights.

Risk	Likelihood (1-5)	Severity (1-5)	Consequences	Mitigations
Circuitry wiring comes loose during flight	3 – The rocket experiences a maximum of 8.1 g, which cause easily cause wires to become disconnected.	3 – All of the electronics will have multiple connections points for many components.	Failure of payloads or subsystems in each payload. Loss of power to avionics.	All connection points will be securely soldered. Batteries and components will be either zip tied or screwed to the payload sleds to prevent movement.
The electromagnetic waves sent out by the CubeSat cannot be detected	3 – The XBee transceivers are able to communicate with each other and send data but can still lose connection.	4 – Data cannot be collected if the radio waves are not detected, this includes GPS data.	Failure of Tesseract payload, possible loss of nose cone section and CubeSat without GPS data.	Multiple tests, in various layouts within the CubeSat have been completed. Tests will be continued until the official launch to calibrate the XBee transceivers to get the best results.

Hazards

Electronic Safety

Most electronic components have not be made permanent yet so much of the soldering is not complete. All testing was done using breadboards.

Due to the abundance of electronics components in all systems of the rocket and their cost, the team will handle all electronics with extreme care. No powered components will be handled without wearing an anti-static wristband. All batteries will be stored where they will not reach below -10 °C or higher than 50 °C. Soldering of various electrical circuits is also hazardous. Before the team begins to work on the construction of payloads, the safety officer will give a briefing on how to avoid burns while using the soldering irons. Only those whose soldering skill is approved by the team leader, safety officer, and one other member will be allowed to work on the soldering the components to mitigate both hazards to the team member and the electronics.

Welding Safety

The CubeSat was constructed from aluminum square bar welded together into a frame. All construction that requires welding is complete. Welding would only be required for repairs to the CubeSat during the remainder of this project. All welding was done by the Citrus College CAPE Owls team. Members of the CAPE Owls have completed the safety test required by the Citrus College Automotive department to weld on campus. All welding was done in the Citrus College machine shop and in the presence of both team's safety officers. Welding masks and gloves were worn at all times during welding. Fire extinguishers are within immediate reach in the event that a fire is caused during welding.

Environmental Concerns

All environmental concerns have been addressed under the vehicle safety section.

V) Launch Operations Procedures

1. Checklist

Recovery Preparation

Table 26: Checklist for Recovery Preparation

Step No.	Details	Check	Safety
1	Untangle shroud lines		
2	Fold parachute		
3	Attach quicklink to recovery harness and parachute		
4	Wrap parachute in protective blanket		
5	Fold recovery harness and wrap with masking tape		
6	Place exposed recovery harness into body tube		
7	Place wrapped parachute in body tube		
8	Attach body tubes		
9	Apply shear pins around designated rocket body		

Motor Preparation

Both the main motor and sustainer were prepared following the directions found on Cesaroni's website at: http://www.pro38.com/pdfs/Pro98_Instructions.pdf.

Table 27: Checklist for Motor Preparation

Step No.	Details	Check	Safety
1	Grease o-rings and place around nozzle		
2	Insert nozzle into nozzle holder		
3	Grease inside of both ends of the motor casing		
4	Insert nozzle holder into motor casing		
5	Place snap ring into motor casing to prevent nozzle holder from sliding out		
6	Insert motor tube into motor casing		
7	Place snap ring into motor casing		
8	Slide motor casing into the motor retainer and install into the airframe of the rocket		

Igniter Installation

Table 28: Checklist for Igniter Installation

Step No.	Details	Check	Safety
1	Inspect igniter head ensuring it is free from cracks and damages		
2	Inspect igniter leads ensuring the wire is not exposed or broken		
3	Slightly bend the igniter lead under igniter head		
4	Use guide to mark igniter depth using a permanent marker		
5	Ensure all switches are in the off position		
6	For the e-match that ignites the sustainer, wrap the e-match around a wooden dowel and tape it, and then place the wooden dowel up through the motor grains until the e-match head reaches the igniter pellet.		
7	Install igniter, ensuring that it is not caught on any fuel grains		
8	Ensure lead of igniter and end of motor casing is at the marked location		

Setup on Launcher

Table 29: Checklist for Setup on Launcher

Step No.	Details	Check	Safety
1	Lower launch rail		
2	Slide booster section onto rail		
3	Slide main airframe onto rail		
4	Attach e-match for sustainer		
5	Put masking tape over sustainer motor		
6	Attach main bay to booster section with shear pins		
7	Raise launch rail to upright vertical position		
8	Attach igniter to main motor		
9	Attach launch system to igniter		
10	Turn switches on		

Launch Procedure

Table 30: Checklist for Launch Procedure

Step No	Details	Check	Safety
1	Clear launch area		
2	Assign team members to watch specific sections of the rocket		
3	Obtain all-clear from Range Safety Officer		
4	Check air traffic		
5	Begin ten-count		
6	Launch!		
7	Keep an eye on all independent rocket sections at all times		
8	Alert any bystanders who may be in the vicinity of possible landing zones		
9	Wait for rocket to land on ground before recovery		

Troubleshooting

Table 31: Checklist for Troubleshooting

Step No	Details	Check	Safety
1	If motor does not ignite, wait five or more minutes before approaching launch pad		
2	Check all connection points between wires that are soldered or fit into place are not loose or faulty		
3	Check for solid points of connection for all power sources		
5	Make sure there is no excess wire when sliding in electronics to minimize the possibility of wires being caught onto all threads		
6	At ground station check to see if GPS units have gotten a lock on the rocket		

Post-Flight Inspection

Table 32: Checklist for Post-Flight Inspection

Step No	Details	Check	Safety
1	Turn of all audible electronics excluding the scoring altimeter		
2	Check to airframe and fins for any type of damages or cracks		
3	Measure the final potential difference across the capacitor in the voltmeter subsystem with a digital multi-meter		
4	Check all electronics onboard for any damages		

2. Safety and Quality Assurance

Table 33: Launch Operations Procedures Risks and Mitigations

Category	Risk	Causes	Consequences	Mitigation
Recovery Preparation	Premature ignition of black powder charges.	Unsafe handling of black powder, open flame or smoking near black powder	Burns or bodily harm.	The safety officer or mentor must be present during the handling of black powder. There will be no smoking within 25 feet of black powder.
Motor Preparation	Premature ignition of the motors	Unsafe handling of the motor, open flame or smoking near the motor.	Bodily harm, severe burns, death.	The safety officer or mentor must be present during the handling of motors. No smoking within 25 feet of black powder.
Igniter Installation	Premature ignition	Connecting the battery to a,	Minor burns, potential to ignite the motor	Igniters are inserted and connected to long wires which are only connected to the power supply once everyone has moved to a safe distance and the countdown has finished.
Launch Rail Setup	Launch rail falls over	Launch rail not secured with guide lines. (depending on the rail used)	Potential injury to personnel and damage to the rocket and rail.	Rail provided by NASA will be used. As many members as allowed out to the rail will set up the rocket. Launch day checklist will be carefully followed so the rocket is completely ready to go out on the launch pad so no extra setup is required.

The safety officer, Joshua, is responsible for all procedure checklists during the launch day procedures. The team holds pre and post briefings for each launch to go over and improve procedures. The team will continue testing of all components to further calibrate all the systems.

The team will ensure that the launch site is always left clean with no trash or debris. All hazardous materials will be disposed of correctly based on the relevant MSDS reports.

VI) Project Plan

1. Budget Plan

Table 34: Overall Budget

Budget	Expected Expenses ($)
General Rocket Materials	899.50
Motor Materials	2763.50
Camera and Hazard Detection Materials	436
Tesseract	637
Travel Budget	2000
Total	6736

Table 35: General Rocket Materials Budget Breakdown

General Rocket Materials	Quantity	Expected Cost ($)
Blue Tube 6 inch diameter	3	118.50
Fin Material (Baltic birch plywood)	6 sheets	80
Fiberglass nose cone 6 inch diameter	1	100
Centering Rings	5	35
Motor Tube	2	31
Payload Bay	1	50
Miscellaneous (couplers, transitions, etc.)	N/A	100
Black Powder	1 pound can	30
Fiberglass & Resin	N/A	40
Igniters	N/A	15
Epoxy	N/A	150
Misc. Sensors	N/A	50
Misc. Wireless Equipment	N/A	100
Total		899.50

Table 36: Motor Materials Budget Breakdown

Motor Materials	Quantity	Expected Cost ($)
Parachute material ripstop nylon (36 inches by 60 inches)	13	58.50
Shroud line	100 yards	30
Shock Cord	69 ft.	140
Shock Cord Protector	3 sleeves	60
18 inch Parachute Protector	3	30
Main motor (First in line motor) Cesaroni K1620 – Vmax	4 Reloads	520
Sustainer (Second in line motor) Cesaroni L985TT	4 Reloads	680
Animal Motor Works Motor Casing 54-2550	1 Casing	150
Cesaroni Motor Casing Pro98 1 grain	1 Casing	380
Raven3 microcontroller	3	465
RockeTiltometer 2	1	250
Total		2763.50

Table 37: Hazard Detection Budget

Camera and Hazard Detection Materials	Quantity	Expected Cost ($)
Raspberry Pi Model B with Pi camera module	1	78
RockSoul Webcam	1	17
L2 Recovery Tether and Sheath	1	106
Adafruit Ultimate GPS breakout board	1	35
Misc. equipment (nylon cords, antennas)		200
Total		436

Table 38: Tesseract Budget

Triboelectric Effect Materials	Quantity	Expected Cost ($)
Hack HD Camera	1	160
Humidity/Temperature Sensor	1	17
Arduino Mega 2560	1	60
Transceiver XBee Pro 900MHz	2	76
microSD Shield	2	30
Single Axis Accelerometer	1	30
Altitude/Pressure Sensor	1	15
11200mAh External Battery Pack	1	28
16 GB Micro SD Card	3	60
EM-406A GPS	1	40
GPS Shield	1	15
900kHz Duck Antenna RP-SMA	2	16
9V to Barrel Jack Adapter	1	3
Carbon Paint	1	20
Polycarbonate Sheet	600 sq. inch	57
Rectangular Aluminum Bar	48 inches	6
Square Aluminum Bar	60 inches	4
Total		637

Table 39: Travel Budget

Travel Accommodations	Quantity	Expected Cost ($)
Hotel expenses	3 rooms,4 nights	1500
Gas	5 tanks of gas	500
	Total	2000

2. Funding Plan

The Rocket Owls have raised a total of $7080 of its $11,000.00 goal. The team set up a donations page on their web site with options for people to fund a specific part of the project or fund any amount to be applied to the rocket. Through various donations, both monetary and in the form of supplies, the team has funded almost the entire cost of the project so far.

The team would like to thank the following sponsors for their support and generosity:

- Rick Maschek
- Professor Lucia Riderer
- Professor Brian Waddington
- Dr. Eric Rabitoy, Dean of Physical and Natural Sciences
- Citrus College Foundation
- Citrus College RACE to STEM
- Fuller, John and Norsleter
- Faraj, Juma and Elina
- Jermaine Wilson
- Popla International Inc.
- Saiful/Bouquet Consulting Structural Engineers, Inc.
- Friends Foundation
- Glendora Public Library

The funding chart below outlines the funding of the project thus far.

Table 40: Fundraising Breakdown

Funding	Brief description	Date	Expected amount ($)	Percentage of final goal (%)	Current amount ($)	Percent received of expected (%)
Citrus College Foundation	Existing grant awarded for completing the 2012-2013 rocket project	Existing	$3,000	27.3%	$3,000	100%
Local Business Donations	Monetary donations as a source of solicitation	Ongoing	$2,000	18.2%	$1,000	50%
Private Donations	Monetary donations as a source of solicitation	Ongoing	$1,000	9.1%	$500	50%
Physics Department Donations	Supply donations received from Citrus College Physics Department	Existing	$1,800	16.4%	$1,800	100%
STEM Event Fundraisers	STEM fundraising/outreach activities	Ongoing	$1,800	16.4%	$1,815	100.8%
STEM Presentation Awards	Monetary awards	Ongoing	$0	0%	$600	
Fundraising activity	Applebee's fundraiser	Upcoming	$400	3.6%	$0	0%
Fundraising activity	Misc. activities such as car washes, bake sales, raffles	Ongoing	$1,000	9.1%	$0	0%
California Space Grant	Awarded to Citrus College Rocket Owls	Existing	$0	0%	$1,500	
		Total Expected	$11,000	Current amount	$10,215	92% funded

3. Timeline

November 2013
December 2013
January 2014
February 2014
March 2014
April 2014
11/10 11/17 11/24 12/1 12/8 12/15 12/22 12/29 1/5 1/12 1/19 1/26 2/2 2/9 2/16 2/23 3/2 3/9 3/16 3/23 3/30 4/6 4/13 4/20 4/27
Task Name
1 Project
2 Manufacturing
3 25% Scale Prototype Construction
4 Full-Scale Construction
5 Tesseract
6 CubeSat Chassis Contruction
7 CubeSat Electrical Component Construction
8 Electrometer Electronic Contruction
9 CubeSat Housing Construction
10 Tesseract Component Integration
11 Hazard Detection System
12 Hazard Detection Electrical Component Construction
13 Hazard Detection Housing Construction
14 LVIS
15 LVIS Electrical Component Construction
16 Motor and Electronic Integration
17 Recovery System
18 Main Parachute Construction
19 Drogue Parachute Construction
20 Booster Section Parachute
21 Parallel Motor Parachute
22 Airframe System
23 Body Tubes and Fin Construction
24 Centering Rings, Coupler Tube, and Stuffy Tube Construction
25 Nose Cones Construction
26 Integration of All Rocket Components
27 Outreach
28 Peer-led Rocketry Lab at Citrus College
29 Hands On Workshop with GATE Students at Citrus College
30 Classroom Presentation at Slauson Middle School
31 Classroom Presentation at Ontario-Montclair School District
32 Classroom Presentation at Ontario-Montclair School District
33 Hands On Workshop
34 Hands On Workshop at Citrus College
35 Hands On Information Booth at Azusa Majors Fair
36 Hands On Workshop at Temple City Unified School District
37 Hnads On Workshop at Citrus College Physics Students
38 Hands On Information Booth at HTCC UC Irvine
39 Hands On Workshop at Glendora Public Library
40 Reports and Presentations
41 Proposal
42 Writing
43 Editing and Revisions
44 Submission
45 School Notification
46 Team Teleconference
47 Web Presence Established
48 Preliminary Design Review
49 Writing
50 Editing and Revisions
51 Slide Development
52 Reports and Presentation Posted on Web
53 Presentation Practice
54 Presentation
55 Critical Design Review
56 Writing
57 Editing and Revisions
58 Slide Development
59 Question and Answer
60 Reports and Presentations Posted on Web
61 Presentation Practice
62 Presentation
63 Flight Readiness Review
64 Writing
65 Editing and Revisions
66 Slide Development
67 Question and Answer
68 Reports and Presentation Posted on Web
69 Presentation Practice
70 Presentation
71 Post Launch Review
72 Writing
73 Editing and Revisions
74 Report Posted on Web
75 Testing
76 25% Scale Prototype Test Launch
77 Tesseract Payload Testing
78 Hazard Detection Payload Testing
79 LVIS Payload Testing
80 Full-Scale Test Launches
81 Rocket Launch
Days Completed
Days Remaining
Project Section
Project Subsection

4. Educational Engagement Plan

Within the past four months, the Rocket Owls have participated in numerous community outreaches. In total, the team has reached out to a total of 737 individuals so far, 94% of whom have been 6th-8th grade students.

The Rocket Owls have three main goals for every outreach:

- To spread awareness of the NASA Student Launch competition
- To build lasting relationships within the community
- To inspire students to pursue STEM and rocketry careers

Every outreach event has included some form of evaluation, to gain better insight into how the team's educational engagement events have impacted the community. The overall response has been exceedingly positive so far, with the majority of students at every event indicating that they not only enjoyed themselves, but also gained insight into STEM fields at the same time.

The following table details the different types of evaluation used in the outreaches.

Table 41: Types of Evaluation Used in Outreach

Evaluation Designation	Type
A	Middle School Level: Post Activity Survey Questionnaire
B	Elementary School Level: Pre- and Post- Activity Survey Questions
C	Verbal Feedback

The details of every single outreach can be found in the following table.

Table 42: Outreach and Educational Engagement Events

Event	Activity	Date of Event	Audience	No. of Participants	NASA Outreach Count	Type of Interaction	Location	E.F. Type
Physics Rocketry Lab	Peer-led rocketry lab	12/4/2013	Physics students	43	0	Education, Direct interaction, Grades 12+	Citrus College	C

Event	Activity	Date of Event	Audience	No. of Participants	NASA Outreach Count	Type of Interaction	Location	E.F. Type
Citrus College Research in Science and Engineering (RISE) Workshop	STEM activity - building mousetrap cars	12/14/2013	7th-8th grade Glendora GATE students	24	24	Education, Direct interaction, Grades 5-9	Citrus College	A
Science Class	Classroom presentation, STEM activity – building spaghetti towers	12/17/2013	6th-8th grade Slauson Middle School students	65	65	Education, Direct interaction, Grades 5-9	Slauson Middle School	C
Rocketry Outreach Event	Rocketry Workshop	1/11/2014	6th grade Edison Academy GATE students	19	19	Education, Direct interaction, Grades 5-9	Citrus College	A
			Edison Academy educators (grades 5-9)	1	1	Education, Direct interaction, Educators (Grades 5-9)		
RISE Workshop	STEM activity - building mousetrap cars and egg drop experiments	1/25/2014	6th-8th grade Edison Academy GATE students	34	34	Education, Direct interaction, Grades 5-9	Citrus College	A

Event	Activity	Date of Event	Audience	No. of Participants	NASA Outreach Count	Type of Interaction	Location	E.F. Type
STEM Outreach	Classroom presentation, STEM activity – building spaghetti towers	1/31/2014	6th-8th grade Edison Academy GATE students	147	147	Education, Direct interaction, Grades 5-9	Edison Academy	A
			Edison Academy educators (grades 5-9)	3	3	Education, Direct interaction, Educators (Grades 5-9)		
Science and Technology Day	Rocketry Workshop	2/8/2014	5^{th}-8^{th} grade Glendora GATE students	28	28	Education, Direct interaction, Grades 5-9	Citrus College	C
Azusa 8^{th} Grade Majors Fair	STEM Activity – building paper airplanes	2/27/2014	8^{th} grade Glendora students	373	373	Direct interaction, Grades 5-9	Memorial Park North Recreation Center, Azusa	C
Rocketry Workshop	Rocketry Workshop	3/8/2014	6^{th} -8^{th} grade Emperor Elementary students	25	25	Education, Direct interaction, Grades 5-9	Emperor Elementary	C
			Emperor Elementary educators (grades 5-9)	2	2	Education, Direct interaction, Educators (Grades 5-9)		

Event	Activity	Date of Event	Audience	No. of Participants	NASA Outreach Count	Type of Interaction	Location	E.F. Type
Chinese Institute of Engineers STEM Seminar	STEM Presentation	3/15/2014	Community college students	20	0	Outreach, Direct interaction, Grades 12+	Mount San Antonio College	C
Honors Transfer Council of California – Student Research Conference	STEM Presentation	4/5/2014	Community college students	25	0	Outreach, Direct interaction, Grades 12+	UC Irvine	C
Physics Rocketry Lab	Peer-led rocketry lab	4/9/2014	Physics students	47	0	Education, Direct interaction, Grades 12+	Citrus College	C
Outreach Event	Presentation, STEM Activity – building paper airplanes	4/12/2014	Middle school students	5	5	Education, Direct interaction, Grades 5-9	Glendora Public Library	A
			Interested members of community	20	0	Education, Direct interaction, Grades 12+		
Total number of participants				881	726			

VII) Conclusion

Over the past five months of the Student Launch competition, the Citrus College Rocket Owls have been working diligently to produce the best overall project possible. In order to ensure that Project Lambda has a safe and successful flight on launch day, the Rocket Owls have had to adjust several aspects of the project since its original conception; however, the team regards this as an indication of strength and adaptability, rather than weakness. Despite limited resources, the Rocket Owls have prospered, largely due to the hard work of its members and the invaluable community support. Three full scale test launches have been conducted, with significant results, marking another milestone in the project plan. The Rocket Owls are extremely proud of their progress so far, and the team eagerly anticipates launching Project Lambda on the Salt Flats in May.